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SEISMOLOGICAL SOCIETY
OF AMERICA

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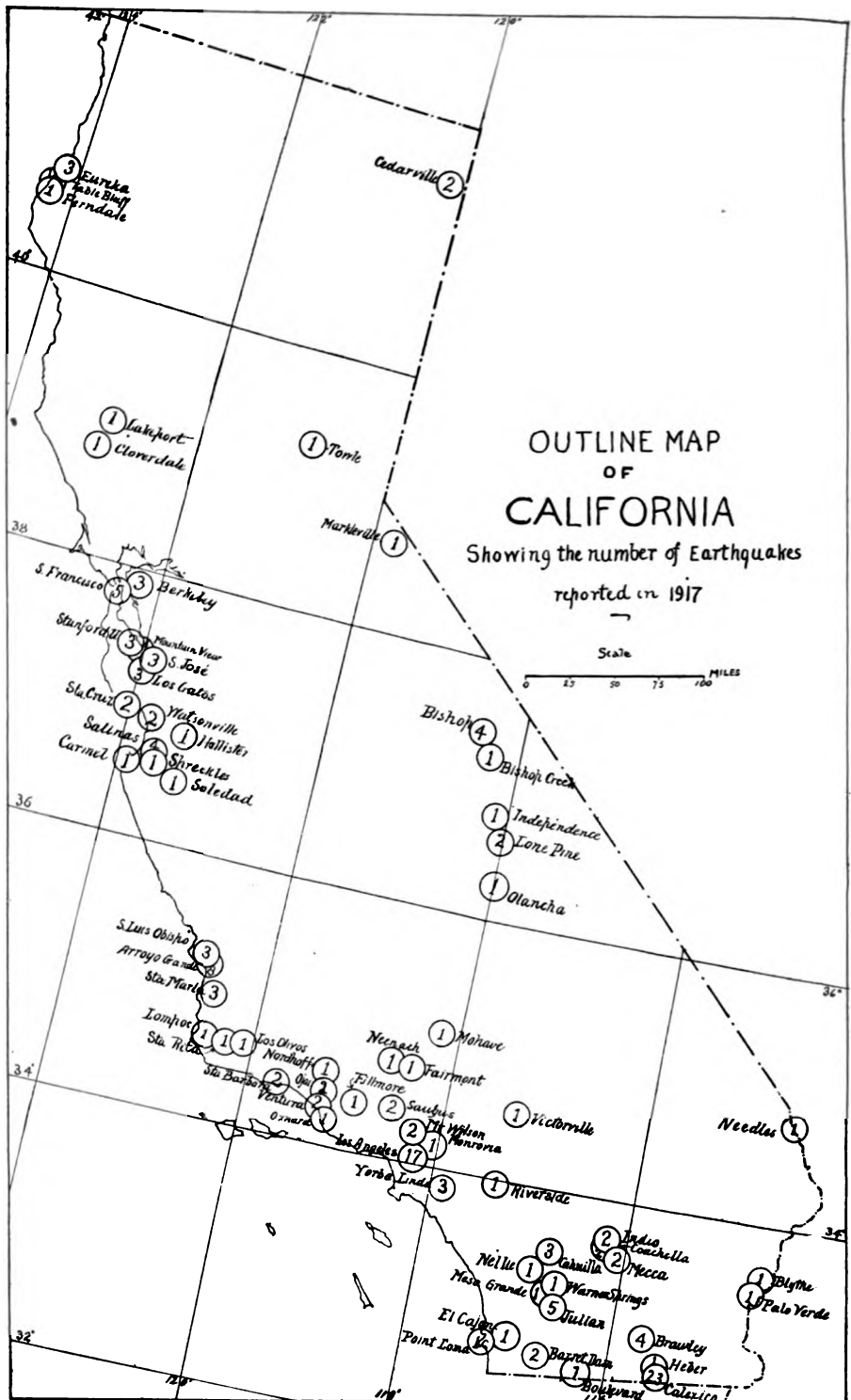
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No. 1

CALIFORNIA EARTHQUAKES DURING 1917

By ANDREW H. PALMER, Observer, U. S. Weather Bureau

Since July 1, 1914, the U. S. Weather Bureau has kept a record of all earthquakes which have occurred in the United States. In addition to records obtained from its own seismographs at Washington, D. C., and Northfield, Vermont, the Weather Bureau receives reports from many other institutions which have seismographs in operation. Moreover, it has the coöperation of more than four thousand voluntary observers in the securing of records of sensible earthquakes, those having an intensity of II or higher in the Rossi-Forel scale. In California the work to date has consisted chiefly of the collection of reports of earthquakes strong enough to be felt by persons. About 350 observers, well distributed throughout the state, have volunteered to coöperate in the collection of earthquake statistics. In addition, publications like the BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA and the daily press are scanned for reports of earthquakes. It is believed that few, if any, earthquakes of sensible intensity escape notice. All reports, instrumental and non-instrumental, received by the Weather Bureau are published in the *Monthly Weather Review*, an official publication.

During 1917 a total of 109 earthquakes strong enough to be felt by persons occurred in California. These alone form the basis of this discussion. This was 43, or 65 per cent, more than the number which occurred during 1916. For the third consecutive year California experienced more earthquakes than all the rest of the United States. During the past year a considerably larger number occurred during the summer dry season than during the winter wet season. From May to October, inclusive, 81, or 74 per cent of the total for the year, occurred, while during November to April, inclusive, the remaining 28, or 26 per cent, were reported. The monthly distribution was as follows:

Number of Earthquakes											
Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	4	7	7	12	29	18	9	6	7	5	2
											109

Of the 109 earthquakes which occurred, 88, or 81 per cent, were so light that they were felt at one station only. The others were strong enough to be felt at two or more adjacent stations. However, at 69 different stations earthquakes were felt at some time or other during the year.

Table I is a summary of all the California earthquake reports received during 1917. The time of occurrence given is the approximate Pacific, or 120th meridian time, and the hours are numbered from 0 to 23, inclusive. Great accuracy of time is not assumed, as the time of observation recorded was, in most cases, that taken from a pocket watch or from an ordinary clock. When an earthquake was felt at a number of stations at about the same time, it is here given as though it occurred at the same minute, though that is not necessarily the case.

As in past years, more earthquakes were noted during the night than during daylight hours. During 1917 a total of 63, or 58 per cent of all, occurred between 6 p.m. and 6 a.m., while but 46, or 42 per cent, occurred during the remaining 12 hours of the day.

Figure 1 is an outline map of California showing the number of earthquakes which occurred during 1917 at the places indicated.¹ It is readily apparent from the figure that earthquakes were more frequent along the coast than elsewhere, and that they were more frequent in the southern half of the state than in the northern. While observers are relatively few in the desert regions and in the high mountains, the map probably gives a reasonably correct distribution of actual occurrences. The region of greatest seismicity was the Imperial Valley, Calexico alone having experienced 23 earthquakes during the year. The region of next greatest seismicity was that immediately south of the Sierra Madre Mountains, with a total of 17 earthquakes in Los Angeles. The region in the vicinity of Monterey Bay, which showed the highest degree of activity in California in 1916, was less active in 1917, though still worthy of note, as six shocks were noted there. San Francisco had five earthquakes, as compared with but one during the preceding year. Five occurred in the immediate vicinity of Humboldt Bay. In the Owens Valley, a recognized epicenter, eight shocks were reported during the year. In the high Sierra Nevada Mountains but one earthquake was felt, while in the

¹ One shock was recorded at Sierra Madre and one at Campbell, neither of which is on the map.

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks No.	Duration Sec.	Sounds	Remarks
Jan.	12 14 42	Fairmont	34°45'	118°25'	3	1	...	None	Recorded on float rain gauge
	12 14 42	Mojave	35 03	118 12	3	1	...	None	
	12 14 42	Neenach	34 47	118 37	3	1	...	None	
	19 5 20	Mt. Wilson	34 13	118 16	2	1	...	None	
	31 21 18	Santa Maria	34 58	120 28	4	2	10	None	Broke mantle in lighthouse
Feb.	9 7 28	San Jose	37 20	121 54	3	1	2	None	
	9 20 30	Olancha	36 16	118 00	3	1	...	Rumbling	
	13 5 05	Los Angeles	34 03	118 15	6	1	...	None	
	13 5 10	Saugus	34 20	118 30	4	1	...	None	Broke mantle in lighthouse
Mar.	3 8 00	Table Bluff	40 39	124 15	6	1	11	None	
	13 7 15	Salinas	36 36	122 40	3	1	...	None	
	18 4 30	Lone Pine	36 37	118 01	4	1	...	None	
	19 0 50	Lone Pine	36 37	118 01	4	1	...	None	Windows rattled
	21 9 10	Bishop	37 22	118 24	4	1	25	Rumbling	
	29 0 06	Fillmore	34 23	118 54	4	1	...	None	
	29 4 59	Stanford Univ.	37 27	122 09	3	1	2	None	
Apr.	2 1 00	Berkeley	37 52	122 16	4	1	1	Rumbling	People awakened
	5 11 00	Lompoc	34 38	120 29	3	1	...	None	
	5 11 00	Santa Rita	34 38	120 16	4	1	...	None	
	12 20 03	Nordhoff	34 35	119 14	5	1	2	None	
	12 20 03	Oxnard	34 12	119 08	5	3	...	None	Windows rattled Concrete tower cracked Dishes rattled Most severe in years
	12 20 03	Santa Barbara	34 23	119 40	6	1	...	None	
	12 20 03	Ventura	34 17	119 17	4	2	...	None	
	13 4 30	Cedarville	41 32	120 08	3	1	60	Faint	
	15 22 00	Cedarville	41 32	120 08	3	1	...	None	Rumbling
	18 15 43	Calexico	32 41	115 30	3	2	5	Rumbling	
	20 22 59	Santa Barbara	34 23	119 40	4	2	...	None	
	20 22 59	Ventura	34 17	119 17	4	1	...	None	
May	11 14 36	Markleeville	38 42	119 46	5	1	...	None	People awakened
	11 14 36	Towle	39 14	120 48	5	2	8	Rumbling	
	17 22 06	Calexico	32 41	115 30	3	1	1	Rumbling	
	18 22 35	Yorba Linda	33 51	117 50	5	2	3	Faint	
	18 23 19	Yorba Linda	33 51	117 50	4	3	3	Faint	Shook buildings
	20 1 45	Yorba Linda	33 51	117 50	5	1	...	Rumbling	
	24 14 00	Needles	34 50	114 36	3	1	...	None	
	24 14 00	Palo Verde	33 26	114 42	3	1	...	None	
	27 1 30	Brawley	32 59	115 40	5	1	...	Loud	People frightened Lifting motion noted
	27 22 07	Barrett Dam	32 40	116 40	5	1	...	None	
	27 22 07	Blythe	33 35	114 38	3	1	...	None	
	27 22 07	Brawley	32 59	115 40	6	1	...	Loud	
	27 22 07	Calexico	32 41	115 30	5	2	...	Rumbling	

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.—*Continued.*

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks	Duration Sec.	Sounds	Remarks
May	27 22 07	Coachella	33°40'	116°10'	5	2	42	None	
	27 22 07	Indio	33 43	116 12	4	1	60	None	
	27 22 07	Julian	33 05	116 37	5	2	20	Rumbling	
	27 22 07	Mecca	33 34	116 05	5	1	...	None	
	27 22 07	Mesa Grande	33 11	116 42	3	1	2	Rumbling	
	27 22 07	Nellie	33 22	116 52	4	2	10	Faint	
	27 22 07	Point Loma	32 43	117 15	3	1	3	None	
	27 22 07	Riverside	33 58	117 21	5	1	...	None	People awakened
	27 22 07	Warner Sprgs.	33 17	116 37	3	1	60	None	
	27 23 05	Calexico	32 41	115 30	3	1	12	None	
	28 2 17	Julian	33 05	116 37	5	1	10	Rumbling	
	30 18 10	Brawley	32 59	115 40	5	1	...	None	
	30 18 10	Calexico	32 41	115 30	3	2	1	Rumbling	
	30 20 35	Cahuilla	33 32	116 43	5	1	4	None	
June	2 6 30	Victorville	34 32	117 18	3	1	...	None	
	5 21 00	Saugus	34 20	118 30	3	1	...	None	
	7 7 41	Calexico	32 41	115 30	3	1	1	None	
	7 16 30	Calexico	32 41	115 30	4	1	3	Rumbling	
	7 22 13	Calexico	32 41	115 30	3	2	1	Faint	
	8 19 30	Carmel	36 34	121 56	4	1	...	Rumbling	
	8 19 30	Salinas	36 36	121 40	3	1	10	None	Dishes rattled
	8 19 30	Soledad	36 28	121 16	5	1	30	None	
	10 16 20	Calexico	32 41	115 30	3	1	30	Rumbling	
	10 18 13	Calexico	32 41	115 30	3	1	½	Rumbling	
	10 19 54	Julian	33 05	116 37	5	1	5	Rumbling	
	12 20 06	Calexico	32 41	115 30	3	1	1	Rumbling	
	16 22 00	Heber	32 45	115 31	5	1	...	Rumbling	Shook buildings
	18 1 55	Calexico	32 41	115 30	4	3	...	Rumbling	People awakened
	18 6 21	Calexico	32 41	115 30	2	1	1	None	
	21 11 20	Independence	36 49	118 13	5	1	...	None	Rocking motion
	21 20 05	Julian	33 05	116 37	4	1	7	Loud	
	24 12 00	Los Angeles	34 03	118 15	4	1	...	None	An abrupt bump
	24 12 30	Los Angeles	34 03	118 15	4	1	...	None	
	25 20 15	Los Angeles	34 03	118 15	4	1	...	None	Buildings jarred
	25 20 24	Los Angeles	34 03	118 15	5	1	...	None	
	26 3 51	Los Angeles	34 03	118 15	3	1	3	None	Trembling motion
	26 5 26	Eureka	40 38	124 11	4	1	3	Rumbling	
	26 13 15	Los Angeles	34 03	118 15	6	1	...	Rumbling	Sounds preceded shock
	26 13 20	Los Angeles	34 03	118 15	6	1	...	None	Rocking motion
	26 13 30	Los Angeles	34 03	118 15	6	1	...	None	Trembling motion
	26 22 26	Calexico	32 41	115 30	4	1	¼	Rumbling	Noise preceded shock
	28 21 50	Los Angeles	34 03	118 15	4	1	1	Rumbling	Abrupt bumping shock
	28 22 25	Los Angeles	34 03	118 15	4	1	...	None	

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.—*Continued.*

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks	Duration Sec.	Sounds	Remarks
June 29	16 00	Los Angeles	34°03'	118°15'	4	1	...	None	Trembling motion
July 30	15 38	Los Angeles	34 03	118 15	4	5	1	Rumbling	
6	3 01	Owenyo	36 40	113 01	7	1	...	None	Broke aqueduct
7	12 57	San Luis Obs.	35 18	120 39	3	2	7	None	Rattled windows
7	12 57	Arroyo Grande	35 18	120 37	6	1	5	Roaring	Trembling motion
7	13 02	Arroyo Grande	35 18	120 37	6	1	5	Roaring	Trembling motion
7	13 15	Arroyo Grande	35 18	120 37	6	1	5	Roaring	Trembling motion
7	19 20	Santa Maria	34 58	120 27	3	1	10	None	
8	3 29	Arroyo Grande	35 18	120 37	4	1	...	None	Trembling motion
8	21 15	Bishop	37 24	118 26	3	1	...	Rumbling	
9	14 22	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Dishes overturned
9	14 22	San Luis Obs.	35 18	120 39	4	1	2	Loud	
9	14 38	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Rocks rolled down hillsides
9	16 43	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Chimneys damaged
9	16 45	Arroyo Grande	35 18	120 37	7	1	5	Rumbling	Trembling motion
15	11 05	Mt. Wilson	34 13	118 16	4	2	2	Rumbling	House creaked
15	11 05	Monrovia	34 08	118 00	4	1	2	Loud	Twisting motion
15	11 05	Sierra Madre	34 11	118 02	4	1	2	None	Trembling motion
15	22 50	Calexico	32 41	115 30	2	1	½	Rumbling	Sounds before shock
17	15 15	Los Angeles	34 03	118 15	4	1	...	None	Rocking motion
17	15 19	Los Angeles	34 03	118 15	4	1	...	Rumbling	Buildings swayed
17	15 30	Los Angeles	34 03	118 15	4	1	...	None	
21	8 50	Ferndale	40 35	124 16	3	3	...	None	
26	0 31	Los Olivos	34 39	120 07	4	1	25	Roaring	Trembling motion
26	0 31	San Luis Obs.	35 18	120 39	3	1	2	None	
26	0 31	Santa Maria	34 58	120 27	5	3	15	None	Moved furniture
Aug. 2	20 20	Cahuilla	33 32	116 43	4	1	3	Rumbling	
3	2 10	Los Angeles	34 03	118 15	3	1	...	Rumbling	Sounds like thunder
12	3 00	Coachella	33 40	116 10	5	1	...	Roaring	Rocking motion
18	22 00	Boulevard	32 38	116 15	3	1	1	None	
18	23 10	Julian	33 05	116 37	5	2	8	Rumbling	
27	16 35	Bishop	37 22	118 24	5	4	...	None	
28	0 40	Bishop	37 22	118 24	4	1	1	None	People awakened
28	0 40	Bishop Creek	37 15	118 17	3	1	...	None	

TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, CALIFORNIA, 1917.—*Concluded.*

Day 1917	Approx. time 120th mer.	STATION	Approx. lat. (N)	Approx. long. (W)	Intensity R-F	No. of shocks No.	Duration Sec.	Sounds	Remarks
Aug.	31 11 20	Ojai	34°25'	119°12'	4	1	1	None	
	31 12 25	Ojai	34 25	119 12	4	1	1	None	
Sept.	4 15 57	Calexico	32 41	115 30	3	1	...	None	
	8 11 01	Calexico	32 41	115 30	3	2	½	Rumbling	
	12 3 26	Berkeley	37 52	122 16	3	1	...	None	
	12 3 26	Los Gatos	37 12	121 58	2	1	10	None	
	12 3 26	Mountain View	37 23	122 05	3	1	...	None	
	12 3 26	San Jose	37 20	121 54	2	1	5	None	
	12 3 26	San Francisco	37 48	122 26	3	1	3	Faint	
	12 3 26	Santa Cruz	36 57	122 02	2	1	3	None	
	12 18 14	Eureka	40 48	124 11	4	2	...	None	Windows rattled
	24 13 21	Campbell	37 17	121 57	3	1	...	None	
	24 13 21	Hollister	36 50	121 20	4	1	8	None	
	24 13 21	Los Gatos	37 12	121 58	3	1	15	None	
	24 13 21	Salinas	36 36	121 40	3	1	5	None	
	24 13 21	San Francisco	37 48	122 26	3	1	3	None	
	24 13 21	Santa Cruz	36 57	122 02	4	2	4	None	
	24 13 21	Stanford Univ.	37 27	122 09	3	1	15	None	
	24 13 21	Watsonville	36 55	121 46	4	1	...	Faint	
	25 10 34	Calexico	32 41	115 30	2	1	½	None	
Oct.	2 23 40	San Francisco	37 48	122 26	4	3	...	None	
	11 13 26	Salinas	36 36	121 40	4	1	2	None	
	11 13 26	Spreckels	36 35	121 38	3	1	1	Rumbling	
	13 16 50	San Francisco	37 48	122 26	2	1	...	None	
	16 15 50	Calexico	32 41	115 30	3	2	6	None	
	22 22 00	Cahuilla	33 32	116 43	2	1	½	Rumbling	
	26 1 18	Berkeley	37 52	122 16	3	2	...	None	
	26 1 18	Los Gatos	37 12	121 58	4	1	8	None	
	26 1 18	San Francisco	37 48	122 26	3	1	2	None	
	26 1 18	San Jose	37 20	121 54	5	2	9	None	
	26 1 18	Stanford Univ.	37 27	122 09	3	1	5	None	
	26 19 49	Eureka	40 48	124 11	2	1	1	None	House creaked
Nov.	1 5 50	Calexico	32 41	115 30	2	1	...	None	Abrupt shock
	5 1 04	Cloverdale	38 48	123 00	2	2	2	Faint	
	5 1 04	Lakeport	39 02	122 56	2	2	5	Rumbling	
	12 23 50	Calexico	32 41	115 30	3	1	2	Loud	
	19 9 30	El Cajon	32 48	116 58	2	1	...	None	
	19 9 30	Indio	33 43	116 12	4	1	30	Faint	
	19 9 30	Mecca	33 34	116 05	4	2	30	Rattling	
	30 22 37	Watsonville	36 55	121 46	3	1	2	Faint	
Dec.	8 1 45	Calexico	32 41	115 30	4	1	5	Rumbling	
	20 0 25	Barrett Dam	32 40	116 40	3	1	...	None	
	20 0 25	Brawley	32 59	115 40	4	1	...	Faint	
	20 0 25	Calexico	32 41	115 30	4	2	5	None	
									Abrupt shock People awakened

plateau region of northeastern California two shocks were reported. On the other hand, not a single earthquake occurred during the entire year in the great interior valleys of the Sacramento and the San Joaquin Rivers,—a noteworthy fact considering the large expanse of territory and the large number of observers resident there.

INTENSITY

Since many of the earthquakes were felt at two or more adjacent stations, the reports received number more than the actual number of earthquakes, it being understood, however, that there is but one observer reporting for each individual station. Classified as to intensity, the 162 reports received during the year testified as follows: II, 14 reports; III, 55 reports; IV, 52 reports; V, 26 reports; VI, 10 reports; and VII, 5 reports. As in past years, the severest shocks did not occur at the places of most frequent disturbance. The lightest shocks were the most frequent. Of the 23 earthquakes which occurred at Calexico, all but one were of intensity IV or less.

NUMBER OF SHOCKS

But one shock accompanied most of the earthquakes. The data presented were as follows: 1 shock, 129 reports; 2 shocks, 25 reports; 3 shocks, 6 reports; 4 shocks, 1 report; and 5 shocks, 1 report. When a report of an earthquake contained no reference to the number of shocks, it was assumed that but one occurred. If more than one occurred it was believed that the observers would have been sufficiently impressed to record the fact.

DURATION OF SHOCKS

In regard to the duration of shocks the reports received during 1917 presented the following evidence: 1 second or less, 21 reports; 2 seconds, 14 reports; 3 seconds, 10 reports; 4 seconds, 2 reports; 5 seconds, 15 reports; 6-10 seconds, 14 reports; 11-20 seconds, 6 reports; 21-30 seconds, 6 reports; 31-40 seconds, none; over 40 seconds, 4 reports.

SOUNDS

Of the 162 reports received, 99, or 61 per cent, made no mention of sounds having been observed before, with or after the shocks. In the 63 cases where sounds were heard, they were described as follows: rumbling, 40 reports; faint, 11 reports; loud, 6 reports; roaring, 5 reports; and rattling, 1 report.

NOTES ON INDIVIDUAL EARTHQUAKES

While there was no earthquake of special prominence in California during 1917, a few are worthy of mention. In the order of their occurrence, these were as follows:

April 12th. At 8:03 p.m. a severe shock was felt simultaneously at Nordhoff, Oxnard, Santa Barbara, and Ventura. The intensity was estimated at IV to VI in the various places mentioned. At Santa Barbara it was the most severe in years, while at Nordhoff it was sufficiently strong to crack a concrete tower. No sounds accompanied this vibration. As these stations are situated in close proximity to the San Luis Obispo and Santa Ynez faults, the shock was probably due to movement of the crust along either or both of these.

May 11th. At 2:36 p.m. the only earthquake reported in the Sierra Nevada Mountains during the year was felt from Markleeville, Alpine County, altitude 8,000 feet, to Towle, Placer County, altitude 3,704 feet. At the former station but one shock occurred, while at the latter two distinct vibrations were felt. At both places the intensity was estimated at V. A segment of the Major Sierra fault-system traverses this region.

May 27th. The most widely felt earthquake of the year occurred at 10:07 p.m. on this date. It was preceded by a shock felt only at Brawley during the early morning of the same day, and it was followed by another one felt only at Calexico at 11:05 p.m. The shock which occurred at 10:07 p.m. was felt at 13 different stations extending entirely across southern California, from Blythe to Point Loma. Its intensity varied from III to VI. At Brawley, where it was most severe, and the first heavy shock in almost a year, it caused some walls to crack. People were frightened, and at a school where commencement exercises were in progress several women and children fainted as a result of hysteria. At four of the stations at which it was observed two distinct shocks were felt. The duration of the vibrations appeared to be unusually long, for at Indio and Warner Springs they were observed to continue through about 60 seconds of time. Mr. Wendell P. Hoge, of the Solar Observatory, Mount Wilson, wrote with reference to this shock:

This earthquake was observed by Astronomer Dr. Harlow Shapley while observing with the 60-inch telescope. Star image oscillated rapidly back and forth in field of view in eyepiece. Two shocks close together were observed. Neither Dr. Shapley nor myself felt the shocks.

Mr. A. McConoll, agent for the Southern Pacific Company at Coachella, wrote in regard to the same earthquake:

Had been threatening for some time. A very unsteady feeling could be felt for some minutes after, as if to start again. Sky to southeast very peculiar for nighttime. Noticed by all.

June 24th-30th. Los Angeles experienced marked but local seismic disturbances during the last seven days of June, when twelve distinct earthquakes occurred. However, most of them were light, no damage was done, and many residents of the city were unaware of their occurrence. Each disturbance consisted of but one vibration of brief duration. Three of the shocks which occurred within an interval of 15 minutes on the afternoon of June 26th were estimated to have an intensity of VI.

July 6th. What was probably the most severe earthquake of the year occurred in the Owens Valley at 3:01 a.m. on this date. This shock had an intensity estimated at VII. It caused a break 160 feet long in the concrete flume of the Los Angeles aqueduct at a point between the Haiwee reservoir and Owens Lake, in Inyo County. Under the direction of Mr. William Mulholland, Chief Engineer of the aqueduct, the damage was temporarily repaired by bridging the break with steel pipe. Since that time the flume has been rebuilt and reinforced. The water supply in Los Angeles was not cut off, because the break occurred above the Haiwee reservoir, which has a capacity sufficient for the storage of several weeks' supply of water for the city. In commenting upon this earthquake the San Francisco Chronicle published the following editorial on July 17th:

This is important to the people of this city, for we are also preparing to bring water from the Sierra. It is known that there is an old fault between us and the Sierra and in the earlier plans for the Hetch-Hetchy enterprise two conduits were planned through the danger zone as insurance against interruption of supply.

If it should appear that these breaks in the Los Angeles aqueduct, occurring on the same day, were due to seismic disturbance we should know it in order that in building our own works we may take the necessary precautions, which may be two conduits and extra strength through the danger zone.

Since we have come to understand that an earthquake is nothing but the slipping of the earth for a few feet along some fault in the rocks, that phenomenon has lost most of its terror. The mischief that any earthquake of which there is human experience can do can be prevented by proper construction. The burning of San Francisco was due to improper construction of the main water

conduit supplying the city. We must take no more chances. If it appears that an earthquake damaged the Los Angeles tunnel, we must see to it that the danger is guarded against in our own enterprise.

July 7th-9th. The marked seismicity noted in the Owens Valley on July 6th seems to have migrated to the region of San Luis Obispo the following day, for nine earthquakes occurred in that vicinity in the three days, July 7th-9th, inclusive. These were disturbances of considerable energy, with intensities of VI to VII. The well recognized San Luis Obispo fault traverses this region and the movement was doubtless along this fault. Each of the nine earthquakes of this period consisted of but one shock, and none lasted more than ten seconds, and most for five seconds or less. The activity seemed to reach its climax on the afternoon of July 9th, when four distinct jars occurred at Arroyo Grande, in Lopez Canyon, ten miles southeast of San Luis Obispo. These shocks were violent and caused creaking of buildings and a decided swaying of hanging objects. Dishes were overturned, rocks rolled down the hillsides, and chimneys were cracked.

July 15th. On this date an earthquake of intensity IV was felt at 11:05 a.m. at Mount Wilson, Monrovia, and Sierra Madre. On Mount Wilson the houses creaked, at Monrovia a distinct twisting motion accompanied by a loud noise was perceptible, while at Sierra Madre a trembling motion was observed. In connection with this earthquake, Mr. Wendell P. Hoge, of the Solar Observatory, remarked:

Weather partly cloudy, wind south, 3 miles per hour, humidity about 30%, temperature 87°. General character of the weather for several days such as is often spoken of as earthquake weather.

The term "earthquake weather" is often encountered in California, but meteorological text-books do not mention it. Those who use the term are unanimous in referring to a condition of hot and calm weather, without much cloud, but usually with more or less haze. The condition is not greatly unlike that which usually precedes a summer afternoon thunderstorm in the Middle West. As the term "earthquake weather" has not yet become commonplace in scientific literature it would be interesting to learn what seismologists think about the matter.

July 26th. An earthquake sufficiently vigorous to move furniture occurred at 12:31 a.m. on this date at Los Olivos, San Luis Obispo, and Santa Maria. At Los Olivos, where the intensity was estimated at IV, it consisted of but one shock of about 25 seconds' duration, which

was accompanied by a roaring sound and trembling motion. At Santa Maria, where the intensity was estimated at V, it consisted of three vibrations, lasting about 15 seconds, and no sounds were heard. In reporting this earthquake, Mr. Roy E. Collom, of Santa Maria, added the following comment:

Had impression of short foreknowledge of unusual event which might have been due to sounds. Writer retired at 10:30 p.m., was unable to sleep continuously because of feeling of depression and was awake at time of shock. This was the most vigorous shock I have felt since 1906. Talked to several people this morning (July 26th); all were awakened by the shock, and former San Franciscans have same impression, relative to vigor, as the writer.

September 12th and 24th. An earthquake which indicated movement along the San Andreas fault occurred at 3:26 a.m. on September 12th. It was felt at San Francisco and Berkeley on the north, southward throughout the Santa Clara Valley, and also at Santa Cruz, on Monterey Bay. It consisted of but one vibration of intensity II to III, and no sounds accompanied it except at San Francisco, where faint sounds were noted. A second earthquake of similar nature was felt throughout the same region at 1:21 p.m. on September 24th.

GENERAL CONSIDERATIONS

From a seismological standpoint the year 1917 was a normal year in California. While there were many minor shocks, few of high intensity occurred. No persons were injured either directly or indirectly as a result of the earthquakes. The total property damage for the year did not exceed \$1,000 in value. The distribution of the earthquakes, their frequency, and intensity were all about as may be expected in an ordinary year in California. The high seismicity of the Imperial Valley is worthy of special attention, and indicates that another destructive shock may occur there at any time. The growing seismicity of Los Angeles and vicinity is also noteworthy, for 17 shocks occurred there, compared with but four during the preceding year. If the theory that a great earthquake is preceded for months and years by an increasing number of light shocks has any valid basis, the two regions mentioned will be worthy of special attention by seismologists in the immediate future.

Lassen Peak (lat. 40° 25' N., long. 121° 45' W.) which showed marked vulcanism in 1915, and occasional activity in 1916, continued to decline as an active volcano in 1917. No California earthquake which

has occurred during the past three years can be related even remotely to this most recent cycle of activity.

Through coöperation with the seismographic station of the University of California in Berkeley the Weather Bureau has been interested to learn what proportion of sensible earthquakes reported to the Bureau has been recorded on the seismograph. It was found that nearly all of the earthquakes felt in northern California were automatically recorded by the seismograph at Berkeley, while but few of those which occurred in southern California were so recorded. None of the many light shocks which occurred in the Imperial Valley were sufficiently strong to affect the university instrument.

The earthquake hazard is well recognized by residents of California, and it is a factor which is considered by careful investors. Earthquake insurance is in growing demand. However, owing to the absence of trustworthy statistics in the past, rates have been more or less arbitrary, and most of them have no scientific basis. Moreover, through a gentlemen's agreement among California newspaper editors the subject of earthquakes is tabooed in the daily press. The general public promptly plunges into a kind of hysteria when a severe earthquake occurs, but soon relapses into complacent indifference to the subject when the immediate danger is over. A seismologist can therefore expect but little sympathy or support in the serious investigation of earthquakes. Furthermore, cities which have recently suffered damage from earthquakes seem to have benefited but slightly from their experience. San Francisco has learned its lesson in the matter of fire protection in a region of high seismicity. But projecting cornices and signs on buildings, overhead wires, and numerous other features indicate that much still remains to be learned and put into practice before earthquakes are rendered harmless. In the meantime the Weather Bureau will continue to gather and to publish earthquake statistics which it is hoped will eventually be of some use to the general public.

San Francisco, Cal.

January 21, 1918

EARTHQUAKES IN THEIR RELATION TO THE LOS ANGELES AQUEDUCT

SYNOPSIS OF REMARKS BY WM. MULHOLLAND¹ BEFORE A MEETING OF
THE SOUTHERN SECTION AMERICAN INSTITUTE OF MINING EN-
GINEERS, LOS ANGELES, CALIFORNIA, JANUARY 7, 1918

There are scarcely any natural phenomena that appeal with greater force to the human mind than do earthquakes. This is quite natural for the reason that the human faith that looks to the solid ground and surrounding hills as being among the most permanent things in Nature, receives a severe shock when these things of accepted permanence shake and quiver. Until quite recent years, the real cause of earthquakes was a subject of discussion even among our learned geologists. The records indelibly written in the rocks themselves, however, have lately led to a very definite conclusion as to their cause. The speaker emphatically disclaims any real authoritative knowledge of earthquakes, further than that which has come to him by the experience common to nearly all here present, of having felt some of the more recent remarkable shocks which have occurred in this state, and the observations afforded him for study of the disturbed, fractured and dislocated condition of the rocks encountered in his every-day work as a civil engineer.

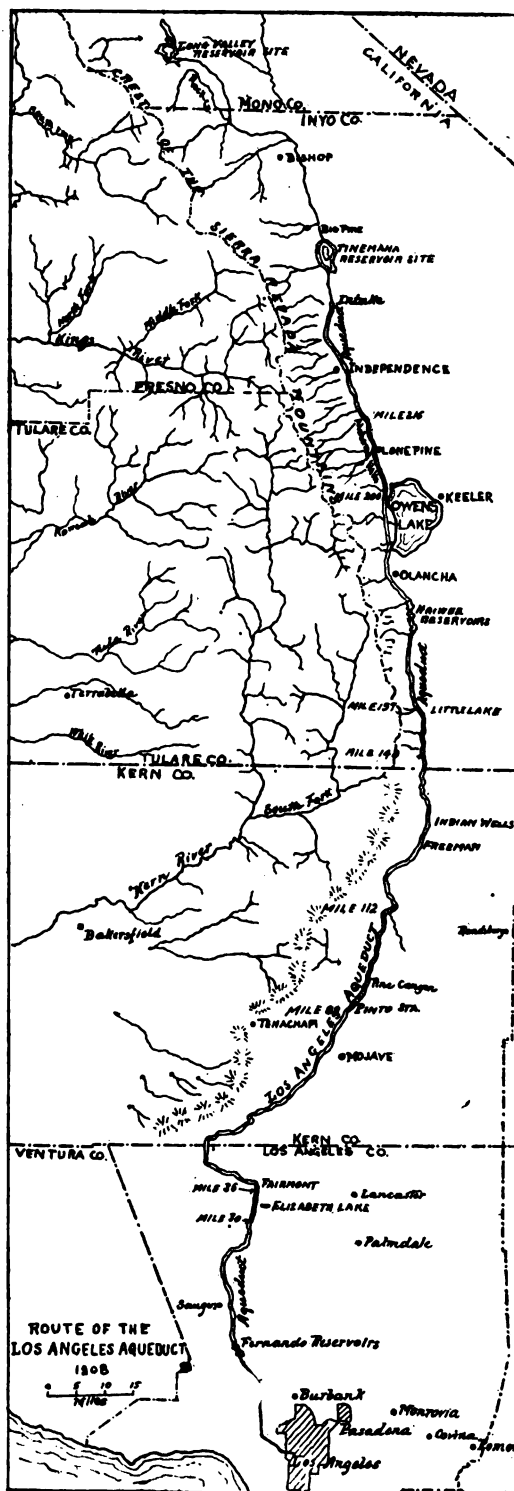
Even the ordinary layman, if of an observant turn of mind, cannot but be impressed, even though he has never felt an earthquake, with the fractured and disturbed condition of the strata of the more recent sedimentary rocks that obviously were laid down by the action of water, and necessarily in approximately horizontal beds. Observing as he must, the condition of broad areas of these rocks up-tilted, folded and fractured as disclosed by sectional views of them in canyons or artificial cuts, such as for railroads, road-ways, and so on, it would be a dull mind, indeed, which would not conclude that these contortions of the solid crust of the earth could not have been produced without disturbances that would be observable to the human senses,

¹Designer and builder of the Los Angeles aqueduct, Chief Engineer of the Los Angeles Bureau of Water Works and Supply.

especially when the movements occurred in the hard and unyielding rocks, as well as in those of more pliant nature.

The building of the Los Angeles aqueduct offered unusual opportunity for the observation of dislocations in the rock system of the country through which it passes, for the reason that in its 238 miles of length, fifty-three miles of which is in tunnels,—its course is crossed by and through the theater of geologically recent disturbance. It is to be regretted that, during the period of the aqueduct construction, the Engineering Corps lacked the services of a qualified geologist to note the geological manifestations disclosed by this great undertaking.

Just to mention a few of the interesting features, I will refer to the route of the aqueduct. It will be noticed that from Mile thirty to thirty-six, the aqueduct passes, by a tunnel, through the mountains forming the southerly rim of the Antelope Valley,—this range terminating at the west in the Coast Mountain mass, of which Mount Fraser is the dominant peak, and forming a continuation of the Sierra Madre Range, toward the southeast. This tunnel is called the Elizabeth Tunnel, by reason of the fact that it passes transversely across the valley in which lies Elizabeth Lake, at a depth of nearly four hundred feet below its floor. The Elizabeth Lake Valley, so called, is a portion of the depression of the San Andreas fault line, which is one of the major earth fractures on the Pacific Coast, west of the Sierra Nevada Mountains. At this point it runs approximately parallel to the ridge of the mountain range in which it exists, splitting it length-wise, with, roughly, about one-quarter of the mass lying to the north of the fault. Naturally, the curiosity of the aqueduct engineers was aroused, as to what would be revealed by the tunnel across the great fracture. At the northerly end of the tunnel, as it dives under the mountain, the formation is granite, somewhat decomposed and dissected by complex criss-cross fractures which rendered the ground quite blocky and made timbering necessary. However, before reaching the region of the fault, the rock became quite sound and compact. Crossing beneath the fault rift, the formation was found to be sheared with fair regularity into vertical leaves of variable thickness, with the fractures showing some slight degree of openness. The planes of fracture strike parallel with the direction of the Elizabeth Valley. This condition of fracture prevailed entirely across the valley, a distance of about three-quarters of a mile, and had all the appearance of a sunken block that in the stresses of movement had been sheared piano-key fashion for



this whole distance. At the south of the fractured mass the mountain was found to be sound and compact,—the rock changing in character toward the south end of the tunnel, to a most beautifully knurled, banded gneiss. This rock was so tight in places as to be absolutely devoid of water and required in some instances the use of sprays to settle the dust after each round of shots was fired.

As the aqueduct passes from the mountains, which are the easterly extension of the Tehachapi Range, but which are known locally as the Pinto and Jawbone Mountains (Mile 89 to Mile 112), there is considerable evidence of quite recent faulting along the joint line between the alluvial formation of the valley and the mountain. In many cases there are jogs of as much as four to ten feet, appearing transversely in the high-pitched, cloudburst-formed debris cones of minor gorges issuing from the hills. This region is very arid, the rainfall not averaging more than three or four inches per annum. The most of this is in the form of violent cloud-bursts of very short duration, hence the fragmental discharges of the short canyons form cones of very steep pitch, the streams that create them always being, during their short existence, in an overloaded condition. It was the speaker's good fortune to witness two of these during the period of aqueduct construction. In both instances the discharge looked more as though some titanic concrete mixer had been discharged in the canyon than that the effect was one of purely rainfall precipitation. In one case, among many smaller stones, an angular block of granite of fully two cubic yards in volume appeared to be floating half submerged in the mass. The speaker cannot say from where this block was started, but it certainly came a mile or more and was finally deposited in the aqueduct. It is such fans as these that are quite numerous farther to the east than where this happened, which show transverse steps continuously across many of them for miles.

Passing from this region, the aqueduct emerges after a series of fourteen miles of tunnels on to the elevated west end of Salt Wells Valley, striking the mountains again back of Indian Wells, from which point it skirts the rim of the mountains, ascending higher and higher, until what is known as the Little Lake region is reached (Mile 150 to Mile 157). The Salt Wells Valley portion of the aqueduct consists of some cut and cover work on the flank of the mountains and some tunnels in good sound rock through the projecting spurs. The drainage lines are usually deeply eroded canyons crossed by inverted

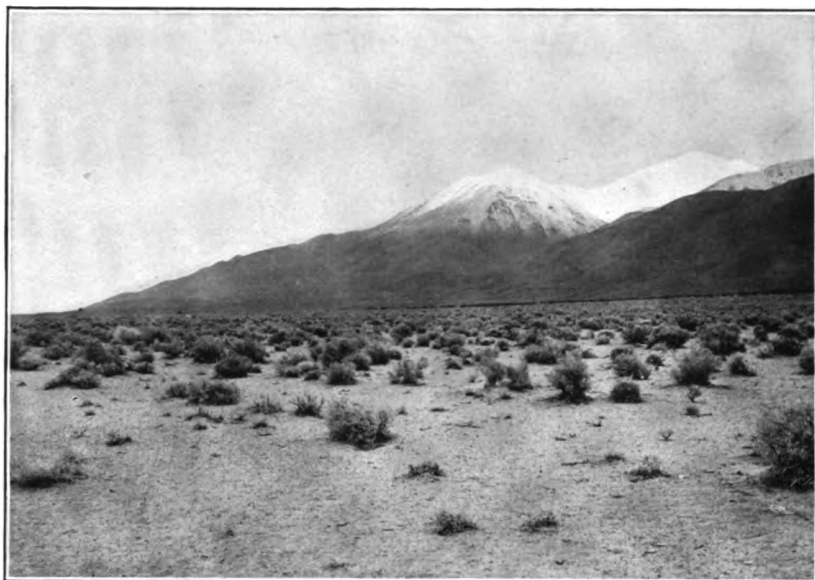


Figure 1. Scarp and detached slipping mass of mountain at Little Lake, looking south from Rose Valley.



Figure 2. Same as Figure 1, looking north from upper end of Salt Wells Valley.

siphons. The mountain face of this region for a distance of sixteen miles displays a topography that indicates a mature and restful condition, the rough features of the mountain being quite effectively concealed by the sands of wind and weather erosion, giving generally soft outlines to the contours. This loose material, however, forms but a very thin cover, so thin in fact that all the cut and cover work of the aqueduct for the whole distance is founded in the rock.

Riding over the wagon road along the floor of the valley, as one approaches the Little Lake region, three features are conspicuously presented in the view looking north. By reference to the map it will be noticed that the Sierra Nevada, which here begins to assume form, takes a bend ten to fifteen degrees westerly. The ancient bed of the older Owens Valley drainage forms the thalweg of the valley and bears evidence of the violence of the torrents that passed through here into the ancient lake bed of the Salt Wells Valley and thence into the lake bed of the Searles Valley, from which the waters were dissipated southeasterly toward the Colorado River. The most striking thing about this old stream bed is its apparent freshness. Its appearance gives rise to the belief that it is occasionally flooded even at the present day. An examination of its bed farther north, however, dispels this delusion, as in its passage through the twelve miles of Rose Springs Valley from the Haiwee gorge to Little Lake, its sands and gravels are smoothly covered to a depth of from four to ten feet by sage and greasewood and aeolian drift.

Another conspicuous feature is the evidence of violent volcanic eruption on the immediate easterly banks of the ancient stream, the lavas being over 150 feet thick in places along the scarp of the stream bank and spreading radially from the group of volcanic cones lying to the east over an area of seventy or eighty square miles.

Viewing in perspective the Sierra Nevada Mountains on the west, there appears conspicuously a slide scarp originating near the very top of the ridge and a very marked step jutting easterly therefrom, which forms the skyline of a huge detached mass. The nose of this mass as it comes down to the old river bed, although much dissected by minor gulches, has the characteristic bluntness usually observable in rock slides. The displacement as shown on the scarp above, however, leads one to the conclusion that the displacement of this mass, which is five or six miles long by a mile or more wide, is only partly due to a slipping down with relation to the parent mountain, but rather to the

mountain itself having been raised, leaving this as a detached member.

The aqueduct was carried through this mass from Mile 148 to Mile 156 in tunnels. The rock was nearly wholly granitic, occurring in thick alternating beds of dark coarse grained granite, hard and blocky, interspersed with masses of short grained pinkish granite with complex shearing planes presenting slippery faces. The impressive thing was the looseness of texture of the whole mass which in places showed a tendency to open fissures.

The aqueduct was pitched in elevation about 400 feet above the base of the mountain, and as before stated, was necessarily wholly in tunnels due to the rough, loose and entirely unreliable condition of the formation at the surface. In one of the gulches near the base of the mountain there was a small spring of so-called soda-water. The three tunnels in the immediate vicinity of this spring were driven with extreme difficulty owing to the presence of carbon dioxide gas issuing from the open texture of the rocks. A remarkable feature of this manifestation was that the amount of gas varied with the barometric pressure. When the barometer was high the gas gave little trouble, but with a drop of any considerable degree, even the two strong twelve-inch blowers employed for ventilation were found at such times, to be inadequate to keep the air pure enough for the men to work.

This is the section of the aqueduct on which seismic disturbance is most frequent, the tremors not being at any time violent, but of such a nature as to give the impression that the main mountain above is still rising and that the oscillations are due to the lagging drag of this detached mass.

After passing this difficult region, nothing of seismological interest is encountered until the neighborhood of the Alabama Hills, above Owens Lake, is reached (Mile 200 to Mile 216). This was the scene of the great earthquake of 1872. The fault created by this shock, which had a vertical displacement in one place of about fifteen feet, passes closely along the aqueduct and loops across it at two points about three miles apart. Sufficient movement has taken place on this fault since the aqueduct was completed, without human observation of shock, probably being nothing more than slight superficial adjustments, to break the concrete in the aqueduct to such an extent that repairs were necessary. It was comforting to observe, however, that this particular fault is the only one noticeable in that portion of the valley that is of recent occurrence, and as the climate and rocky char-

acter of this ground are both favorable to the long preservation of the evidences of crustal disturbances, it is to be hoped that a period of comparative rest has been reached in this region. The scarp of 1872 looks as fresh as though it had occurred but yesterday, while evidences of movements antedating that one seem to indicate quite a remote period of time since their occurrence.

It must be borne in mind that this brief discussion is the result of the mere observation of a layman, and anything in the way of conclusions here made might be materially modified and differently construed by the studies of an experienced geologist.

EARTHQUAKES IN SOUTHERN CALIFORNIA¹

By HOMER HAMLIN

During the past year I have been trying to collect data and records pertaining to earthquakes in southern California. At the outset I thought we might have eight or ten shocks; if it were a good year for earthquakes. In all, over fifty shocks have been recorded; but even these are not all, for I am sure that many slight shocks have passed unnoticed, or were not considered important enough to report. The effort is worth while and the work should be carried on even if it is rather strenuous at times, for we shall never solve our own earthquake problems until we study our own territory.

I will very briefly describe the location of some of the so-called earthquake regions in southern California, note some of the shocks which have occurred in past years, according to the scant records, and then those felt within the last year or so.

The San Andreas Fault.—That part of the so-called San Andreas fault which traverses southern California, extends southeasterly from the Tejon Pass along the southern border of the Mohave Desert, through the Cajon Pass, along the southern side of the San Bernardino Mountains, through the San Geronio Pass north of San Jacinto Mountain, and probably extends southeast along the desert mountains northeast of the Salton Sea to the Gila Mountains east of Yuma, Arizona, and on into the state of Sonora, Mexico.

Many earthquakes have originated along this fault, but only a few will be mentioned. In the vicinity of the Tejon Pass the San Andreas fault is intersected by the Tehachapi fault, which extends northeasterly at least eighty miles. Earthquakes seem to be unusually numerous and severe near this junction.

In 1852 an earthquake opened fissures in the ground for a distance of not less than thirty miles in the Tejon Pass region. Later in the same year, 1852, a violent shock was recorded at Yuma, Arizona. It threw down part of Chimney Rock, now known as Picacho Peak, and opened

¹Read January 7, 1918, at the meeting of the American Institute of Mining Engineers at Los Angeles, California.

fissures in the clay desert bordering the Colorado River. Shocks were felt almost daily for many months. The mud springs, forty miles southwest of Yuma, now known as Volcano Lake, were also active, indicating that slipping also occurred on the adjacent San Jacinto fault.

In 1857 a violent earthquake was felt from Yuma to Sacramento. The waters of Mokelumne River were thrown out upon the banks, leaving the bed dry in one place. The current of Kern River was turned up stream and the stream overflowed its banks. The waters of Tulare Lake were thrown upon its shores. Water in the Los Angeles River was thrown out of its bed. Houses were thrown down in San Fernando and San Diego. Fissures were opened in the ground in the San Gabriel Valley and in San Bernardino Valley. At and near Fort Tejon, in the vicinity of Tejon Pass, buildings were thrown down, large trees overthrown or broken down, and the earth was fissured for a distance of forty miles. Ridges several feet high were formed and the beds of streams changed.

In 1868 a severe earthquake fissured the earth near Dos Palms, not far from Indio.

The earthquake of October 22, 1916, was the hardest and most widely observed shock of the year in California. It was felt from near Fresno to San Diego and from east of Mojave to the coast, over an area of 28,000 square miles, and was recorded instrumentally at the seismographic station of the University of California. Near the epicenter, in the vicinity of Tejon Pass, it was violent enough to break limbs from pine trees, roll rocks down the mountains, throw goods from store shelves, break dishes and cause very general alarm. The earth was very slightly fissured. The main shock was followed by seven after-shocks within a few hours, and by a decided shock a few days later.

During 1917 shocks have been reported from Palo Verde Valley, Needles, Yuma, Coachella, Victorville, and adjacent regions. All of these shocks probably originated on the San Andreas fault.

San Jacinto Fault.—The San Jacinto fault apparently branches off the San Andreas fault west of the Cajon Pass in the Lytle Creek region. It has a more southerly trend than the San Andreas fault, crosses the San Bernardino Valley between Colton and San Bernardino, passes along the west side of San Jacinto Valley, southwest of San Jacinto Mountain, crosses the mountains to the southeast, appears

in the Imperial Valley, borders the northeast side of the Cocopa Mountains, and apparently extends into the Gulf of California.

About twenty-five miles to the southwest of the San Jacinto fault is another lineament known as the Elsinore fault. It extends from the Puente Hills toward the southeast, passing southwest of Elsinore, through the Warner Ranch country near Julian, along the west side of the Imperial Valley, *west* of the Cocopa Mountains in Mexico, and to the Gulf of California.

Many earthquakes have been reported from the region traversed by these parallel faults, but we have no data, among the older records, which show to a certainty which fault slipped. I am of the opinion that slipping occurred on both faults, and possibly on the San Andreas fault also, at or about the same time in some cases. The records do show, however, that severe earthquakes have occurred here; a fact further attested by the evidence furnished by fault traces and topographic forms.

A fault-slip on the San Jacinto lineament caused the Imperial Valley earthquake of April, 1915. The epicenter was in the vicinity of El Centro and Calexico. Many buildings were damaged and six persons were killed in Mexicala. The total property damage is estimated to have been \$900,000.

Another earthquake occurred on the same fault at Volcano Lake in November of the same year. It was severe enough to fissure wet ground. After the shock the mud volcanos along the northeast side of Cerro Prieta, Black Butte, became very active and threw up a column of steam which reached the cloud line and resembled an immense snow bank balanced on a black pedestal.

During 1917 a total of fourteen earthquakes has been reported from the Imperial Valley region. The hardest shock was that of May 27th, which was felt over southern California from Los Angeles to San Diego, also an unknown distance in Mexico, and from the Colorado River to the coast. It was hardest in the Imperial Valley and at San Jacinto, suggesting that the slip occurred on the San Jacinto fault. No damage was done, although the shock was the most pronounced since those of 1915.

Other shocks have been reported from this zone, San Jacinto-Elsinore faults, or near it, from Elsinore, Rincon, Pomona, the region southeast of Hemet, and from Sierra Madre.

Coast Region.—In 1812 southern California was subjected to nearly continuous shocks for four and one-half months. Four days seldom elapsed without at least one shock. Many persons left their homes and lived out of doors.

In October of that year the mission at San Juan Capistrano was greatly damaged and at least thirty persons were killed. San Gabriel Mission was damaged and the top of the tower thrown down. In December of the same year the San Fernando Mission was damaged by a shock, also the Santa Barbara Mission. At Santa Barbara a suspended ball vibrated continually for eight days and at intervals for fifteen days.

In July, 1855, severe shocks were felt in Los Angeles and vicinity. The bells at the Mission San Gabriel were thrown down and two heavy waves rolled in at Point San Juan near San Juan Capistrano.

Our information regarding this series of shocks is so incomplete that it is impossible to say that the slips occurred on any one of many faults. Probably there was a general adjustment of strains over a large area. It should be noted, however, that fault phenomena are conspicuous near San Juan Capistrano and the shock which destroyed the mission could easily have been of local origin. In fact this seems very probable.

All of you know of the low swell or ridge southwest of Los Angeles which extends from the Palms to Dominguez Hill, Signal Hill, and to the southeast of Long Beach. The surface formations exposed are all Pleistocene and in places contain mammalian remains similar to those found in the La Brea beds west of the city. The ridge is of recent origin, geologically, and the forces which have elevated it are apparently still operating.

During 1917 no less than twenty earthquakes have been reported along this range of hills. In every case where the data have been worked up, the epicenter was found to be to the northeast of the hills in the low lands in the southwest part of the city. Evidently faulting or folding is in progress here, and more shocks may be expected. None of the shocks were hard, but those of February 13th and June 9th and 26th were strong enough to be noticed by many persons. No damage was done by any of them.

During 1917 other shocks have been recorded from the vicinity of Saugus and the Santa Clara River Valley.

Sierra Nevada Fault.—The major fault of the Sierra Nevadas is along the eastern front of the range. The escarpment along the western side of this fault zone is most conspicuous in the Owens Valley, where it rises very abruptly not less than 9000 feet above the valley. This lineament is not a single continuous fracture, but a series of parallel or nearly parallel faults, with some divergent branches and with conspicuous dropped blocks between some of the faults. Between Bishop and Owens Lake there are three main faults, the middle one following the valley in a general way.

Many earthquakes have occurred in the Owens Valley; the most notable one of which we have a record was in March, 1872. This shock was very violent and was felt over practically all of California and Nevada and at points in northern Mexico.

The slipping which caused this earthquake was on the middle fault, between Owens Lake and Bishop, and on other parallel faults south of the lake. Fissures were opened from Haiwee to a point north of Big Pine, a distance of seventy miles. In places the ground sank from two to thirty feet, ponds were formed and drainage lines were changed. There was a small tidal wave on Owens Lake. The east shore of the lake was slightly elevated and the west side depressed about two feet so that the road had to be rebuilt. Many adobe houses were destroyed and about thirty persons were killed and sixty injured.

During the past year seven earthquakes have been reported from this region. One in July, the hardest, was felt for about 100 miles along the fault zone.

EFFECTS OF AN EARTHQUAKE IN A MINE AT TOMBSTONE, ARIZONA

By W. F. STAUNTON, Mining Engineer

Evidence regarding the degree to which earthquake vibrations are perceptible below the surface of the ground and the physical effects of such vibrations seems to be very meager. This is doubtless due to the fact that people who have had such experiences seldom take the trouble to record them. The writer has been told by persons who have been in mines during earthquakes of quite marked surface intensity that nothing was felt underground; while others, in other mines, have reported that they were plainly felt. It is possible that both are right, and that the varying testimony is due to differences in rock structure, the neighboring rocks in one case transmitting the vibrations readily and in the other absorbing and deadening them, or possibly they are locally cut off by intervening cushions of inelastic material such as decomposed dikes. It is conceivable also that wave interference may locally cause stationary spots, or there may be nodes. Such phenomena are understood to be recognized by seismologists regarding the surface effects.

The writer has had the experience of being in a mine during an earthquake and it is to record a few observations regarding this experience that these notes are made.

In May, 1887, there was a succession of earthquake shocks, felt pretty generally throughout the southwest, but in more pronounced degree in southeastern Arizona, and to a still greater extent in northern Sonora, Mexico, where considerable damage was done, and where it would have been very great if there had been many large structures in that locality. It was found later that the center of the disturbance was in Sonora, over 100 miles south of the international boundary line. A committee of investigation was sent down to report on the effects of the earthquake, and, as I remember, found a very extensive fracture, open in places, and with vertical displacements of many feet in the walls at intervals. Doubtless the report of the committee can be found in the papers of that time. An account was printed in the

Engineering and Mining Journal of June 11, 1887, covering surface effects in southern Arizona.

It appears to be well established that the vibrations were of sufficient intensity to constitute a fair working test of what earthquake vibrations might be expected to do to mine workings in their paths. At that time the mines of Bisbee and Tombstone were very extensively opened, and there were many miles of underground workings, including many large cavernous open stopes in the limestone, with little timbering. Notwithstanding these conditions, the actual damage underground was only trifling, while on the surface the shocks were sufficient to cause plaster to fall, to throw down chimneys, and disarrange foundations so as to require the resetting of engines.

Up to that time I had always understood that earthquake vibrations were not very perceptible far underground, but I found this to be a great mistake in some cases. In company with an assistant I was engaged on some survey work in a mine at Tombstone in a large inclined open stope about 150 feet below the surface. The first warning was a heavy roaring noise, followed almost immediately by the beginning of vibration which seemed to culminate in a very pronounced jolt. The first impression was that there had been an explosion of some kind, but I quickly recognized the vibrations for what they really were, as I had felt earthquakes before. The loosened rocks from the hanging-wall crashed down with much noise, striking sparks as they came in contact with the hard footwall, and for a few moments our situation was one of considerable danger and such as to leave a vivid mental impression.

At another mine where men were working at a depth of 500 feet, cutting out a chamber in hard limestone about a hundred feet from the shaft, they dropped their tools and rushed for the station, where they needed no urging to come up. They said they thought the mine was caving in, as everything seemed to be moving. One of the men told me that he was standing in a drift in hard white limestone; that he felt impelled to brace himself against the walls to maintain equilibrium, and that he distinctly saw a wave or deflection in the solid rock approach and pass him. He is not an imaginative person, and he has repeated this statement to me within the past few days, as he lives in Los Angeles, and I sought him to question him again about his experiences and sensations.

A man went to find a miner who was working alone in a very soft raise being put up from the 500-foot level, but strange to say, he had noticed nothing unusual and took the warning called up to him as a joke, refusing to come down. The vibrations so apparent in the hard rock seemed to have been absorbed by the softer, spongy rock.

So far as the writer's experience goes, it seems to show that, while earthquake vibrations extend at times to depths of several hundred feet in very pronounced degree, there is little to be feared in the way of material damage to mines from them even when of considerable intensity.

THE STUDY OF EARTHQUAKES IN SOUTHERN CALIFORNIA

By HARRY O. WOOD

The study of earthquakes has barely begun. There lies before us here a great, unexplored domain of nature.

No longer ago than the middle of the nineteenth century ideas concerning earthquakes ruled by the fancy of medieval, and even ancient, days still found respectable place in the world's opinion. However, at that time, Robert Mallet and Alexis Perrey had already set in motion a counter current of rational investigation. Encouraging progress has been made since then, especially during the last fifteen years. But even yet we are barely at the threshold.

We may declare with positive assurance that the expansion and refinement of knowledge about earthquakes will be of great usefulness to humanity, not merely through the development of science, and thence in secondary, ramifying ways, but to human welfare in very direct ways.

Seismology needs, asks for and deserves immediate, greatly increased support—for many and broad reasons.

But how are we to study earthquakes? They are not of hourly or daily occurrence. We cannot produce them at will. And if we could the public would scarcely take a kindly interest in such a method! Also, if they give us any warnings of their coming, as yet we do not understand these well. Therefore, in practice, we cannot experiment with earthquakes. This most powerful method of scientific inquiry is withheld from us. For no artificial disturbance, however great at and about its source, can compare in total energy, or depth of action, with a natural earthquake—even a weak one. Experimentation may assist us in minor ways, as in testing instruments, but the occurrence of earthquakes is too uncertain and too complex to allow much use of it in attacks upon the broader aspects of the problem.

Consequently we must depend upon the adequate, all-around study of natural shocks. Even more than in most branches of science, first-hand experience, observation and measurement of the phenomena of

nature lie at the base of sound progress in seismology. We must study earthquakes where and when they occur,—and, when and *where* they occur we must study them.

Now where *may* we study natural earthquakes? Any community, or any land, may be visited by an earthquake. This is the possibility. But it is not the rule. Almost everywhere the occurrence of an earthquake strong enough to be generally noticeable is the event of a generation, if not of a lifetime or longer, while strong shocks practically never occur. To be sure, in all places, with sensitive seismographic devices we may study the waves of strong earthquakes proceeding from distant lands. Very important knowledge has thus been gained. But the most pressing earthquake problems cannot be attacked and solved in such ways,—those especially which bear most directly upon human welfare. In most places, therefore, only a partial study of earthquakes can be conducted.

On the other hand, we know regions where earthquakes are common,—where weak shocks are frequent, while strong shocks and destructive shocks occur at longer intervals. In all these regions, since the occurrence of shocks in each exhibits peculiarities of its own, the study of seismology is of paramount importance. For it is only in such places that our knowledge of earthquakes can be extended adequately and progress be accelerated at a reasonable pace. Moreover, in these places there is a threat of danger to life and to property,—a condition which demands our best knowledge of the time and place of impending disaster, of how shocks may act to produce destruction, and how their effects may be prevented or minimized,—since their causes and occurrence are beyond human control. In all these regions the study of earthquakes not only affords great opportunities for the advancement of science, which do not exist elsewhere—of which, therefore, we must take full advantage—but it constitutes a public duty on humanitarian grounds as well.

California, and the territory which adjoins it, is such a region. Here both duty and opportunity call. Many problems, and methods of attacking them, are clearly seen. There only is needed an adequate financial basis for undertaking work.

About a year ago there were published two studies dealing with the problems presented in this province. One was an effort to synthesize the crude and imperfect records of past years, and so to indicate the lessons these teach and the problems they pose, and to point

out the directions of inquiry thus suggested. The other stated at some length a plan for the adequate and systematic study of these problems, so far as we can comprehend and visualize them in the present state of knowledge.

This plan, as a whole, was comprehensive. To undertake and carry on the work outlined by it in its more complete form would require considerable income,—hence its proper, enduring support would call for a fairly large endowment. Eventually such support must become available.

But it was not, and is not, deemed wise to undertake the whole program, or even a large part of it, at the beginning. For in early stages of the work abnormally rapid progress is anticipated. At short intervals marked improvements in instrumental equipment should be devised and introduced, necessitating the discarding and replacement of mechanisms already in use. New findings may bring about readjustments of emphasis upon the relative values of different lines of inquiry. New problems must arise, calling for new methods of attack. As a consequence of such advances in knowledge and methods, details of the plan almost surely may be modified with advantage.

So, from the first, for many reasons, growth from a small beginning has seemed the desirable way to put the plan into effect. But here words of warning seem necessary. First, the beginning should be upon a basis adequate to insure progressive work from the outset, otherwise the early results will be sparse and often ambiguous and thus their direct usefulness will be impaired and, worse yet, the promising character of such work will be obscured. In other words, we ought not to begin too modestly. And second, the greater needs of the expanding or complete program should be visualized clearly, and so the earliest foundation should either provide for the future development directly, or, failing that, it should leave the field clear, both in matters of law and in matters of sentiment, for development in future without friction or hindrance.

With all this in mind, a plan for beginning on a much smaller scale was set forth in the study mentioned; and in this it was urged strongly that the work therein indicated should be begun at an early date in southern California.

Why should this beginning be made in southern California? Because, this is a region of much economic importance, and, for the west, a densely populated area where weak earthquakes occur at no

great intervals and where strong and destructive shocks have occurred. Between 1769 and 1857 several very powerful shocks originated here. After 1857 an interval of comparative quiet followed, until 1915 when strong shocks again occurred in the Imperial Valley. We cannot yet make earthquake predictions with confidence, but on the basis of this history, it is the part of wisdom and foresight to expect here the occurrence of strong shocks and a greater frequency of weak shocks in the years of the immediate future. For there is no reason for thinking that the fundamental causes which produce them have declined in action or ceased to operate here. Here, too, is a good place for our undertaking because we have a relatively small region, naturally isolated by sea, desert, and mountain walls, in which our study can be begun and its importance demonstrated, and emphasized, by the establishment and equipment of relatively few seismometric stations, and the conduct of field investigations on a relatively small scale. Here, therefore, relatively small initial income would be required.

The details of this preliminary, subordinate plan, and the discussion of necessary and desirable station equipment, may be found in the published study referred to. There is no need to reiterate this here. But a short general outline may be of immediate interest.

As a first step one station should be established, preferably in the Los Angeles-Pasadena district. (Ultimately the chief station of the system—a station of the first class—should be located here.) At first it is desirable that this station should be equipped with several types of seismometers, including all likely to be serviceable in recording local shocks; and, most important of all, if possible, provision should be made for experimentation and the constructing and testing of more promising types. Only through the use of better types of seismometers than any now known can progress be accelerated at a desirable rate in the study of local shocks. Many types of seismometers now in general use could be dispensed with altogether because:

- (a) they are ill-adapted for registering local shocks, and
- (b) better types than they are known already for the mensuration of waves from distant sources.

Also, from the beginning, means should be available for expeditions and investigations in the field within the area.

Additional stations should be established as soon as means can be found to support them, especially after a type of seismometer suitable for registering local shocks is found or developed. When it is feasible

at least two suitably placed and suitably equipped stations should be added. Little clean-cut, definitive progress can be expected until at least three adequate stations suitably located and spaced have been operating for a time—a length of time which will depend a good deal upon the frequency of earthquakes within the region of sensibility of all three stations. Until we have data of this degree of definiteness and refinement to digest and synthesize, the work will remain in the intuitive and problem-suggesting stage. Definite conclusions must be based upon definite information.

Three adequately equipped stations will serve to locate the positions and depths of origin of all shocks well registered at all three places. All places of origin thus definitely marked must then be related to knowledge of geological structure and peculiarities derived from careful studies in the field.

The desirability of extending the network of stations, at least until all that are needed for the southern California province are in operation, should be obvious without further comment.

The aims of the geological work conducted in the field would be several, among them:—

- (a) to locate systems of faulting upon which shocks do or may originate,
- (b) to determine the mechanisms and surface and structural characteristics of the movements of fault-slipping along these systems,
- (c) to correlate seismometric indications with geologic indications,
- (d) to determine the facts, and then the mechanisms and causes, regarding areal variation in shock effects.

Now at the present time, owing to the world-war, it will be difficult, very likely impossible, to procure seismometers from the usual sources. Certainly no adequate equipment can be bought at the moment. But this need not necessarily postpone the work. For it should be possible, if means are found, to construct and test experimental types—a very important duty of the undertaking—while it is possible that some seismometer might be found with which to begin registration. If such preliminary registration served no other purpose it would afford an idea as to the usual strength and the usual frequency of the occurrence of registrable shocks within a radius of 50 to 100 kilometers of the station.

But not much important progress can be expected to result until seismometric registration with adequate apparatus has been carried on for a time at three stations at least.

A beginning upon the work in the field can be made now as well as later. In fact, a considerable amount of field investigation may advantageously precede work at the seismometric stations,—unless these were to be better equipped than now is possible.

In conclusion it need only be said that the value this work will come to have can scarcely be overestimated. It cannot be done without financial support, for the employment of men and the purchase, construction, and installation of equipment. And the exact needs and exact course of action cannot be completely foreseen.

NOTE ON THE VELOCITY OF LONG WAVES AND THE AVERAGE DEPTH OF THE OCEAN

By HARRY FIELDING REID

The theory of water waves shows that waves, whose wave-length (that is, the distance between successive crests) is many times as great as the depth of the water, advance with a velocity which depends only on the depth of the water and is independent of the wave length. The relation is

$$v = \sqrt{gh} \quad (1)$$

where v is the velocity of propagation of the waves, g the acceleration of gravity, and h the depth of the water. This expression can be used for two purposes; we can determine the velocity of propagation if we know the depth, or we can determine the depth if we measure the velocity.

A. D. Bache, Superintendent of the U. S. Coast and Geodetic Survey, first conceived the idea of finding the *average* depth of the Pacific Ocean by applying this formula, the velocity of propagation being determined by the time taken by sea waves, set up by earthquakes on the Japanese coast, December 23, 1854, to travel to the tidal stations at San Diego and San Francisco.¹

But the application of the formula for determining the *average* depth from the *average* velocity is not justified, as the velocity is not proportional to the depth, but to its square root. It developed later that the average depth determined from this formula was always too small; and this gave rise to various explanations, until Charles Davison pointed out² that the formula would necessarily give too small a

¹"Notice of Earthquake Waves on the Western Coast of the United States on the 23d and 25th of December, 1854." By A. D. Bache, Superintendent United States Coast Survey, in the *American Journal of Science*, 21, 37-43, 1856; and in Report United States Coast Survey, 1855, Appendix 51, pp. 342-346; and again, with slight additions, in 1862, Appendix 24, 238-241. A copy of the tidal records is reproduced with these articles.

²"Note on an Error in the Method of Determining the Mean Depth of the Ocean from the Velocity of Seismic Sea-waves." *Philosophical Magazine*, 48, 33-36, 1897.

depth, because the average of the square roots of the various depths passed over was smaller than the square root of the average depth.

Davison's proof will not be evident to persons not very familiar with mathematical analysis; but his results can be obtained by a very simple procedure. From equation (1) it follows that

$$dt = \frac{ds}{v} = \frac{ds}{\sqrt{gh}} \quad (2)$$

where dt is the time for a wave to pass over the element ds of its course. The time necessary to pass over two elements of the same length, but of different depths, will be

$$dt_1 + dt_2 = \frac{ds}{\sqrt{gh_1}} + \frac{ds}{\sqrt{gh_2}} = ds \left(\frac{1}{\sqrt{gh_1}} + \frac{1}{\sqrt{gh_2}} \right) \quad (3)$$

Let h be the average depth of the two elements and write $h_1 = h + k$ $h_2 = h - k$; then

$$\frac{1}{V} = \frac{dt_1 + dt_2}{2ds} = \frac{1}{2\sqrt{gh}} \left(\frac{1}{\sqrt{1 + k/h}} + \frac{1}{\sqrt{1 - k/h}} \right) \quad (4)$$

where V is the average velocity, corresponding to the total distance passed over divided by the total time taken. This equation gives for the correct average depth of the two elements

$$h = \frac{V^2}{g} \times \frac{1}{4} \left(\frac{1}{\sqrt{1 + k/h}} + \frac{1}{\sqrt{1 - k/h}} \right)^2 \quad (5)$$

whereas Bache, by substituting the average velocity and the average depth in formula (1) got

$$\bar{h} = \frac{V^2}{g} \quad (6)$$

In formula (5), k/h varies from zero, when the two depths are equal, to unity when the smaller depth becomes zero. The following table, which gives the value of the factor $\frac{1}{4} \left(\frac{1}{\sqrt{1 + k/h}} + \frac{1}{\sqrt{1 - k/h}} \right)^2$ for various values of k/h , shows that it is always greater than unity, and therefore the true average value of the depth is always greater than the value obtained from Bache's formula.

k/h	$\frac{1}{4} \left(\frac{1}{\sqrt{1 + k/h}} + \frac{1}{\sqrt{1 - k/h}} \right)^2$
0.1	1.01
0.2	1.03
0.4	1.14
0.7	1.68
1.0	∞

We see that the difference between the two formulae increases as k/h increases: i. e., we may have considerable variations in the depth, if the latter is large, without materially affecting the average velocity; but for shallow depths small variations are important.

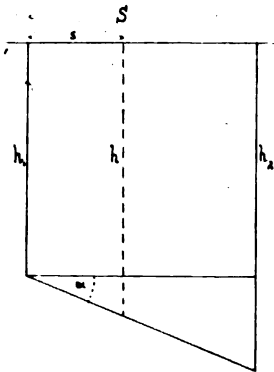
We may divide the path of the wave into pairs of elements and determine the average depth of each pair; if we use Bache's formula, we shall obtain too small an average depth for each pair; therefore, when we combine these pairs to determine the average depth of the whole course, the result will be too small.

To determine the time taken a wave to travel over a course of varying depth, we must integrate equation (2), and this evidently can only be done when we know the relation between h and s : i. e., when we know the distribution of depth. Therefore, the determination of the mean depth by means of the average velocity of a long wave, requires us first to know the depths at all parts of the wave's course; and with this knowledge the mean depth can be determined directly more easily than by means of the mean velocity of the long wave.

Let us see how large an error we make by applying Bache's formula to a uniformly sloping bottom. Let h_1 and h_2 be the depths at a distance apart S ; let $\tan \alpha = p$, then from figure, $h = h_1 + ps$, and equation (2) becomes

$$\int dt = \int_0^S \frac{ds}{\sqrt{g(h_1 + ps)}}$$

$$\therefore T = \frac{2S}{\sqrt{g}} \frac{\sqrt{h_2} - \sqrt{h_1}}{h_2 - h_1} = \frac{S}{\sqrt{g}} \left(\frac{2}{\sqrt{h_1} + \sqrt{h_2}} \right)$$



If h_1 and h_2 differ but slightly in comparison with their average, Bache's formula could be used with small error. As a particular case, suppose h_1 equal to 0; we then have the case of a wave passing from or to a shore line. The true average depth would be $h_2/2$; and from equation (7)

$$h = \frac{h_2}{2} = \frac{2V^2}{g} \quad (8)$$

which is just twice the depth that would be obtained by using Bache's equation.

We cannot use Bache's equation to determine the mean depth of the ocean; but if we know the distribution of depth, we can determine the time taken by a wave to travel between two points. This method was very useful in studying the movement of the water along the English Coast caused by the great Lisbon earthquake³ and made it possible to show that in many places the water was disturbed by the earth vibrations there, and not, as had been supposed, by the sea-waves, which could only have arrived many hours later. In calculating the time taken for a wave to travel over a stretch where the variations of depth are small compared with the depth itself, we may substitute the average depth without much error. In approaching shallow water we should use equation (7).

By comparing the time of arrival of an earthquake shock with the time of arrival of the sea-wave, the origins of some off-shore earthquakes have been estimated. This estimation could be greatly improved by considering carefully the distribution of depth in calculating the time necessary for a sea-wave to travel to the shore from various distances.

Johns Hopkins University,
Baltimore, March 2, 1918.

³"The Lisbon Earthquake of November 1, 1755." *Bulletin Seismological Society of America*, 4, 55-80, 1914.

SEISMOLOGICAL NOTES

Los Angeles, California, November 23, 1917.—There was a shock at 7 p.m. lasting about one second. It was reported by two persons at rest and caused distinct rattling of doors, windows, etc. This shock was in the area in which so many were felt during the year 1917.—Homer Hamlin.

Calexico, California, December 20, 1917.—At 12:23 a.m. a slight shock was felt at Calexico. It lasted from four to five seconds and was noticed by several persons at rest. It caused jarring of buildings, creaking of walls, ceilings, and swaying of suspended articles. It was accompanied by a faint rumbling sound.—Reported by C. N. Perry to Homer Hamlin.

Guatemala, December 25, 1917, to January 26, 1918.—The last number of this BULLETIN briefly mentioned (vol. VII, p. 142) the disastrous earthquakes that destroyed a large part of the city of Guatemala. The shocks began December 25th and continued until December 31st. On January 5th press dispatches reported that the shocks had continued up to that date with varying frequency and intensity. About a hundred deaths had been reported, most of the houses were uninhabitable, and practically the entire population was in the streets. The cathedral, the palace and the postoffice had all fallen, Las Vacas bridge to Barrios was down, and railway traffic between Guatemala and San José had been interrupted by landslides on the line. Some of the adjoining towns had also been badly damaged. The walls of the insane asylum and of the jails were thrown down on the second day, and the patients and prisoners escaped. The cemetery walls in which dead bodies were buried having been thrown down, the coffins and dead were exposed to view. Fortunately no fires broke out among the ruins of the city. It is said that the neighboring volcano of San Salvador recently ceased its customary eruptions, and that the earthquakes immediately followed.

The latest dispatches received in this country on January 26th, report continued shocks and say that the people are leaving the city

of Guatemala; the firm of W. R. Grace & Co. has moved its offices to Esquintla. The suburban railways are still in poor condition. Two thousand refugees are being cared for at the Red Cross camp, and though they have no other shelter, there is no lack of food supplies.

February 25, 1918.—Press dispatches from San Salvador on February 25th state that communications with the interior of Guatemala have been interrupted by violent earthquakes. The exact locality is not mentioned.

Guyaquil, Ecuador, January 10, 1918.—The volcano of Tunguragua in central Ecuador erupted for several days prior to January 10th. It is reported that the town of Baños at the foot of the volcanic peak has been destroyed.

Swatow, China, February 16, 1918.—A violent earthquake occurred at Swatow, China, on February 16th. It seems to have reached a high intensity over a large area that is not clearly defined, but includes Chong Chow. More than a hundred buildings were damaged or quite destroyed, and two hundred persons were killed.

Kilauea, February 28, 1918.—The floor of Kilauea crater was rising on February 28th, and an overflow of lava was expected.

Yakima, Washington, February 28, 1918.—An earthquake was felt throughout the Yakima Valley in Washington at 3:45 p.m., on February 28, 1918. Houses swayed, windows, doors and dishes rattled, but no damage was done.

Los Angeles, March 6, 1918.—A slight shock was felt at 10:25 a.m. on March 6th, through a zone extending across the city of Los Angeles. No damage was done.

Venice, California, March 6, 1918.—A shock was felt by many persons at Venice, California, at 10:21 a.m. on March 6, 1918. There was a rocking movement that lasted from five to seven seconds, and was accompanied by an explosive rumbling sound. There was

some alarm, but no damage was done except the breaking of a few dishes. The intensity is estimated to have been about V of the R.-F. scale.—Dr. James T. Brown.

Venice, California, March 8, 1918.—An earthquake was felt by many persons at Venice, California, at 4:27 a.m. on March 8th. It lasted about two seconds, and was accompanied by a rumbling sound. The intensity is estimated at nearly V of the R.-F. scale.—Dr. James T. Brown.

Spokane, Washington, March 11, 1918.—At Gonzaga University, Spokane, Washington, an earthquake was recorded at 8:26 p.m. on March 11th by the university seismograph. It had an intensity of IV of the R.-F. scale, and lasted about two seconds. It was distinctly felt also at several stations along the Northern Pacific Railway, where walls swayed and doors and windows rattled. It was felt also at Trout Creek and Heron, Montana, and at Cabinet, Clarks Fork, Sant Point, and Rathdrum, Idaho.—A. M. Jung, Seis. Observer.

Sierra County, California, March 12, 1918.—Two sharp earthquake shocks were felt at 2:30 a.m. and at 4:30 a.m. on March 12, 1918, over a large area in Sierra County, California. A few chimneys were thrown down, but no serious damage was done.

REVIEWS

The Bulletin Semestriel de l'Observatoire Météorologique du Séminaire-Collège St. Martial at Port-au-Prince, Haiti, for the months of July to December, 1916, contains the reports of earthquakes registered at the Port-au-Prince seismologic station from September 23, 1916, to August 31, 1917. Out of some thirty-odd shocks recorded, only one, on July 26, 1917, reached an intensity of VI of the R.-F. scale. This shock was felt over most of the island of Haiti. It occurred at 8:11 p.m., and reached an intensity of V or more at several places. At Puerto Plata it lasted seventy-five seconds, reached an intensity of VI, and caused general alarm. At Limonade it lasted fifteen seconds and had an intensity between V and VI. At Cape Haitien the intensity was VI; at Bayeux V; at Port-de-Paix, IV.

Organization and publications of "El Servicio Seismológico Mexicano." Summary of an editorial in the "Boletín Mensual del Observatorio Meteorológico y Seismológico Central de Mexico," No. 8, August, 1916.

The monthly bulletin of the Central Meteorological Observatory of Mexico is primarily a catalogue of the observations of the various seismological and meteorological observatories and stations in Mexico. The bulletin dated August, 1916, contains a brief history of the development of the seismological service of the Republic of Mexico.

In June, 1903, Sn. Ing. Jose G. Aguilera took part in the second conference of the International Seismological Association in order to study the seismic problems, the solution of which requires the coöperation of numerous stations distributed over the world. In 1904 a provisional station was attached to the National Astronomical Observatory and equipped with two Bosch-Omori pendulums of 10 kilos, and further equipment was obtained in 1905.

In 1908 the Servicio Seismológico Nacional was established as a department of the Instituto Geológico. This department was to consist of one central seismological station of the first order and fifty-two of the second order. The equipment of the central station was to include a Wiechert horizontal seismograph of 1200 kgs., a Wiechert vertical seismograph of 1300 kgs., and barographic, hydrographic, and

thermographic instruments. The equipment of the stations of the second order was to be a Wiechert horizontal seismograph of 200 kgs., and a Wiechert vertical seismograph of 80 kgs. and meteorological self-registering instruments.

Due to unsettled conditions in the Republic, the carrying out of the original plan has been delayed and only three stations are in operation. These are the central station, the station at Mazatlan and the station at Oaxaca. The central station was closed February 3, March 23, and August 1 to August 10, 1915, and was then established as a department of the Observatorio Meteorológico Central.

The following is a list of publications of the department:

La zona magaséismica Acambay-Tixmadeje, por F. Urbina y H. Camacho. Boletín 32, Instituto Geológico Nacional.

Parergones del Instituto Geológico Nacional: T. I; T. II, No. 10; T. III, Nos. 3, 8, y 10; T. IV, No. 1; T. V, Nos. 1-3 y 6-8. These contain the catalogue of the earthquakes that have occurred in Mexico between 1904-1912 inclusive.

The Geological Institute will publish the catalogue up to July, 1915, and from this date on, the lists of earthquakes will appear in the monthly bulletin of the Central Meteorological Observatory.

C. F. TOLMAN, JR.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.—Jesuit Seismological Service, Sacred Heart College. Reports nos. 11 and 12, November 1 to December 31, 1917, and nos. 1 and 2, January 1 to February 28, 1918.

La Paz, Bolivia.—Boletín Sismico del Observatorio del Colegio San Calixto (P. P. Jesuitas). Reports nos. 5 to 14, from February 4 to October 5, 1917.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory. Reports nos. 22 to 25, November 1 to December 31, 1917, and nos. 1 to 3, January 1 to February 28, 1918.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 32 to 34, from November 1, 1917, to January 31, 1918, and compiled press dispatches from November 16, 1917, to January 27, 1918.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 13 to 16, August 15 to December 31, 1917, and no. 1, January 3 to 30, 1918.

EUROPE

Coimbra, Portugal.—Boletín Sismico do Observatorio da Universidade, nos. 7 to 9b, October 1 to December 31, 1917, and no. 1, January 1 to 31, 1918.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 25 to 30, August 1 to September 30, 1917.

PUBLICATIONS RECEIVED

Boletín Mensual del Observatorio Meteorológico y Seismológico Central de Mexico, nos. 1-12, Enero-Diciembre de 1916.

Bulletin Semestriel de l'Observatoire Météorologique du Séminaire-Collège St. Martial, Port-au-Prince, Haiti. Janvier-Décembre, 1916.

Boletín Mensual; Oficina Meteorológica Nacional; Republica Argentina. Año 1, nos. 6-12. Buenos Aires, 1917. Año 2, no. 1, 1917.

Anales de la Academia de Ciencias Exactas Fisicas y Naturales: Nueva contribución a la determinación racional de algunas funciones sísmicas, de Galdino Negri. La Plata, 1917. 230 pp.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

- I. **Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. **Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. **Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. **Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. **Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. **Fairly strong shock:** general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.
- VII. **Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. **Very strong shock:** fall of chimneys, cracks in walls of buildings.
- IX. **Extremely strong shock:** partial or total destruction of some buildings.
- X. **Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

Bulletin of the Seismological Society of America

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JUNE-SEPTEMBER 1918

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Fig. 1. Corner view of main business block of San Jacinto. Negative taken April 24, 1918, by S. D. T.



Fig. 2. In same block as Fig. 1 at diagonally opposite corner. On right is wall of concrete building which was not seriously damaged. Negative taken April 25, 1918, by S. D. T.

The Bulletin of the Seismological Society of America

VOL. VIII

JUNE-SEPTEMBER, 1918

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THE SAN JACINTO EARTHQUAKE OF APRIL 21, 1918

By **SIDNEY D. TOWNLEY**

From data collected by Homer Hamlin, A. M. Strong, Frank Rolfe, and the author

INTRODUCTION

On April 21, 1918, the whole of southern California and western Arizona was shaken by an earthquake of marked intensity. The shock came, without sensible foreshocks, at 3:32 p. m. (Pacific Coast Daylight-Saving Time) or 22:32 Greenwich Mean Civil Time. Newspaper reports published on the morning of April 22d indicated that the greatest damage occurred in the small city of San Jacinto, Riverside County, California. San Jacinto is in latitude $33^{\circ} 47'$ north and longitude $116^{\circ} 58'$ west, approximately thirty miles southeast of Riverside and seventy-five miles east by south of Los Angeles. Some of the buildings in Hemet, two miles south of San Jacinto, were also badly damaged. The population of each of these places is approximately 1,000.

INVESTIGATIONS

In accordance with the policy which the Seismological Society of America has adopted of making field investigations of all severe earthquakes occurring within a reasonable distance from San Francisco, the official headquarters of the society, the author of this article, in company with Mr. Homer Hamlin, of Los Angeles, spent three days, April 24th to 27th, in San Jacinto and vicinity, investigating the effects of the earthquake and the geologic formations of the region.

Later, Mr. A. M. Strong and Mr. Frank Rolfe, of Los Angeles, spent from May 5th to 13th making further investigations in the mountainous region to the southeast of San Jacinto Valley. The results of their investigations are published as a separate article in this number of the BULLETIN.

Dr. Ralph Arnold, of Los Angeles, to whom acknowledgment is due for assuming a considerable portion of the expense of these investigations, has made a study of the fault system of the San Jacinto region, and the results of his work are also published as a separate article in this number of the BULLETIN.

For a number of years Mr. Homer Hamlin, at his own expense, has been collecting data concerning earthquakes from all portions of the southern part of California. He has prepared report sheets containing a large number of questions, which are distributed to his correspondents and returned to him properly filled out whenever an earthquake is felt. These reports, and a few others obtained by Messrs. Strong and Rolfe, constitute the data from which the isoseismal curves have been drawn for the map accompanying this article. (Plate 5.)

The reports collected by the U. S. Weather Bureau from its observers in California and Arizona and published in the *Monthly Weather Review* for April, 1918, have also been consulted and used as a check upon the conclusions reached from the data collected by Mr. Hamlin.

TOPOGRAPHY AND FAULT SYSTEM

The topography and the system of faults in the region around San Jacinto are described in Dr. Arnold's article, pages 68-73 of this number of the BULLETIN. The fault system, as worked out by various persons, is given in Plate 13, opposite page 68. Dr. Arnold has drawn the main fault line directly through the city of San Jacinto, and there is considerable evidence to support this location. It is not my purpose to take up a full discussion of the evidence of the location of this fault, but to mention only some of the evidence found by Mr. Hamlin and myself in our visit to the ranch of F. A. Blackburn. This ranch is located in the Bautista Creek Canyon, about eight miles southeast of San Jacinto (San Jacinto quadrangle, sections 26 and 35, 5 S., 1 E.). On the day following the earthquake two boys living in Hemet went into the hills east of the Blackburn ranch and reported the finding of a place where a piece of ground about ten acres in extent had sunk several feet. Mr. Hamlin and I attempted to find this sink, but did not succeed. We did, however, find three old sinks which we considered clear evidence of a fault line. Fresh earth cracks were found around the sides of these sinks and it was probably these which led the boys to think that the whole area of the sink had gone down on April 21st. We saw three of these sinks, but were told at the Blackburn ranch that there were seven. If a line be drawn through Hog Lake, which Messrs. Strong and Rolfe consider topographic evidence of the fault, and the sinks just described, it will pass directly through San Jacinto. (See Plate 6.)

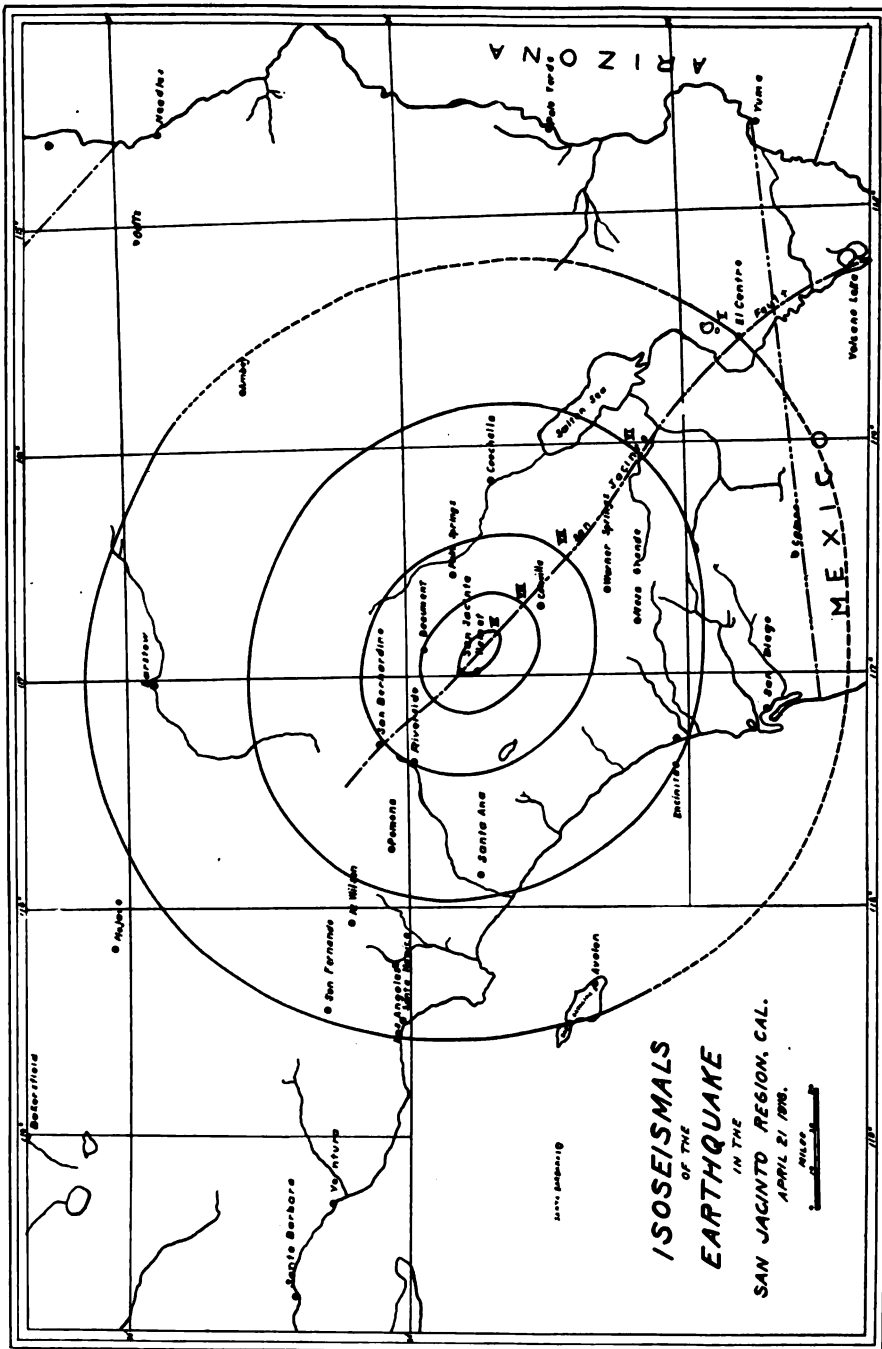


Fig. 3. Isoseismals of the San Jacinto, Cal., earthquake of April 21, 1918.

INVESTIGATIONS AT SAN JACINTO, HEMET, AND VICINITY

By HAMLIN AND TOWNLEY

Damage to buildings.—The greatest damage caused by the earthquake was in the business district of San Jacinto. In the principal business block of the town but two buildings remained standing—a new concrete building and a frame building. The buildings wrecked were mostly brick or artificial stone of poor construction, or old frame buildings. Concrete buildings, substantial frame buildings, and well-constructed brick buildings were not seriously damaged. The damage at Hemet was considerably less than at San Jacinto. No buildings were completely destroyed and none of substantial construction were seriously damaged. The property loss at San Jacinto was estimated at \$125,000 to \$150,000 and that at Hemet not more than \$75,000. Some of the damage wrought is illustrated in Plates 4, 7, 8 and Figure 10, Plate 9. There was also some damage to buildings at various places within a hundred-mile radius of San Jacinto. This damage consisted for the most part of broken plaster, chimneys, and plate-glass windows. The writer did not make any investigation of these damages outside of San Jacinto and Hemet.

Injury to people.—Several persons were injured in the wreckage, but no one was killed. It is fortunate that the shock came on Sunday afternoon when the business districts were deserted, otherwise it is probable that a number of lives would have been lost. The telephone office, located in a one-story frame building, was wrecked by the falling of the second-story brick wall of an adjacent building. The three telephone operators were imprisoned but not injured. (See Plate 7, Figure 6.) Mrs. George Koehler was buried in the wreckage of a second-hand store and rather seriously injured.¹ One man was thrown from his porch and sustained a broken rib. Several persons sitting on the ground at the time of the shock were unable to rise to their feet. Two miners were imprisoned by the caving in of a tunnel in a magnesite mine near Winchester, some ten miles or more southwest of San Jacinto. They were rescued uninjured.

Damage to roads, canals, etc.—The concrete road between Hemet and San Jacinto was cracked in thirteen places. This is a north and south road and the cracks were all approximately perpendicular to the

¹ As this sentence was being written an earthquake was felt by the writer in his office at Stanford University, California, 1918, August 3, 11^h30^m29^s a.m. (6^h30^m29^s Greenwich Mean Civil Time). Intensity, III.

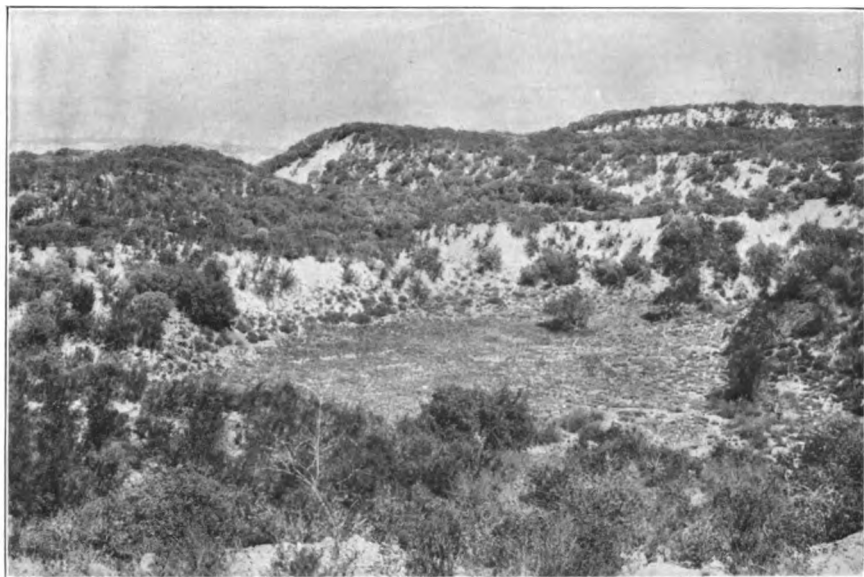


Fig. 4. Sunken area along San Jacinto fault trace, one mile east of Blackburn Ranch, between Bautista Canyon and San Jacinto River. Negative taken April 26, 1918, by H. H.

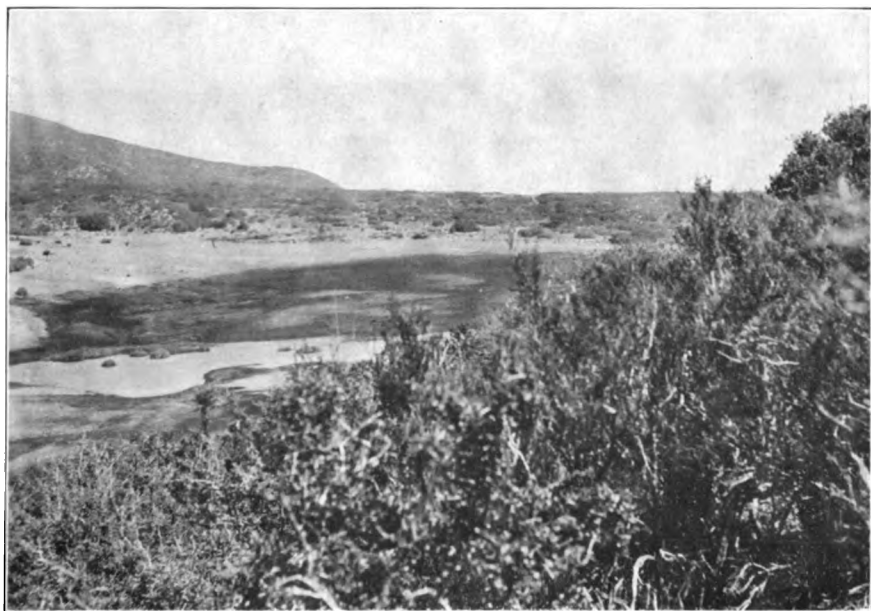


Fig. 5. Hog Lake. Looking south and showing spur of Thomas Mountain. Negative taken May, 1918, by F. R.



Fig. 6. Damage in San Jacinto, in same block as Plate 4. Center building is the telephone office. Negative taken April 24, 1918, by S. D. T.



Fig. 7. Moving-picture theater, San Jacinto. built of artificial stone. Front of building fell into street. Negative taken April 25, 1918, by S. D. T.



Fig. 8. First National Bank and other damaged buildings, Hemet, Cal. Negative taken April 24, 1918, by S. D. T.

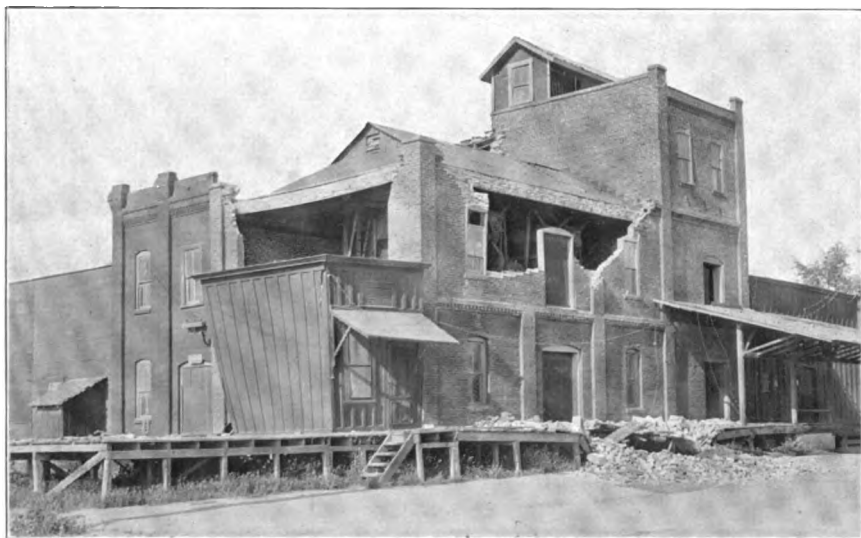


Fig. 9. Flour mill, Hemet, Cal. Negative taken April 24, 1918, by S. D. T.



Fig. 10. Power house at Idyllwild, in San Jacinto Mountains, fifteen miles east of Hemet. Negative taken May, 1918, by F. R.

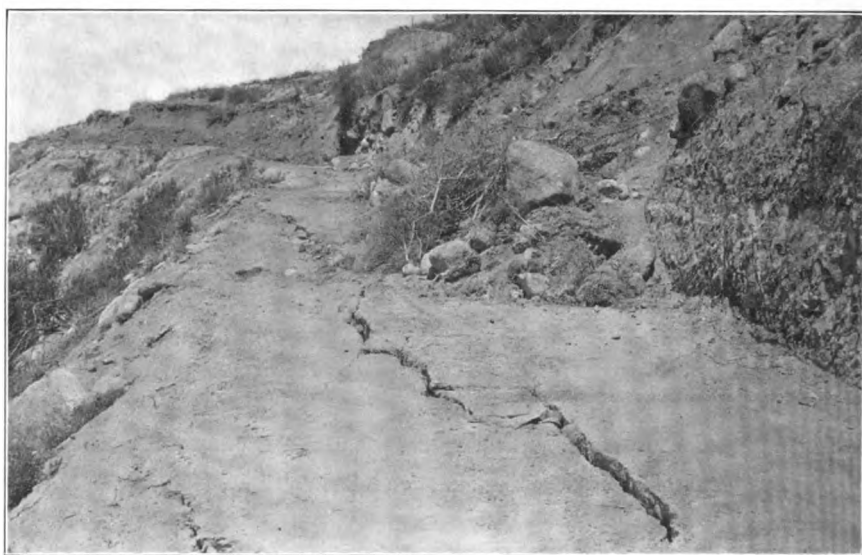


Fig. 11. Small landslide and crack in road, about ten miles east of Hemet. Negative taken April 25, 1918, by S. D. T.

direction of the road, probably occurring at the natural cleavage places in the concrete. No cracks were found in the earth at the sides of the road. In the main concrete road running northwesterly from San Jacinto there were several cracks of a much more serious nature. These were also perpendicular to the direction of the road. At one place about a mile northwest of the center of town the concrete was buckled and a section about three feet wide torn up. The alignment of the road was altered to the extent of about three inches. (See Plate 10, Figure 12.)

Concrete irrigating canals were broken at a number of places near San Jacinto and Hemet. At the Blackburn ranch the owner said that a concrete flume 2,000 feet long was broken, on an average, every six feet.

About a mile northwest of San Jacinto a silo, some thirty or forty feet in height and some twelve feet in diameter, was overturned, falling to the west. At a number of places in this same region live limbs were broken from trees. A cemetery is located about half-way between San Jacinto and Hemet. A detailed inspection was not made, but by driving around two sides practically all of the cemetery could be viewed. But one monument was seen to be overturned—a surprisingly small number when the severity of the shock is considered.

Ground cracks.—Cracks in the ground were found in four different localities, but it is believed that they were all due to the shaking and that none of them indicates a surface slip along the main line of the San Jacinto fault.

(a) The only cracks found in the immediate neighborhood of San Jacinto were in an alfalfa field on the ranch of A. McCleish, about a mile northwest of the center of San Jacinto, the field being adjacent to the road where the worst break was found as described above. There were several cracks ten to twenty feet long and approximately parallel to the direction of the road, and to the direction of the main San Jacinto fault as drawn by Dr. Arnold. His location of the fault shows these cracks to be very close to it. The ground here is low and flat—alluvial soil.

(b) About four miles southeast of San Jacinto and half a mile northwest of Vallevista numerous cracks were found along the banks of the San Jacinto river bed. My notes taken at the time read as follows: "Found many slides on banks of San Jacinto River; sandy soil cracked in places parallel to banks of river or to incoming gorges;

cracks in places as much as twenty feet back from banks." These cracks are close to the fault line, although probably due simply to the shaking.

(c) On the road to Strawberry Valley, about five miles east-southeast of Vallevista, numerous cracks were found in the mountain road. These had various directions and are believed to be due to the violent vibrations. These cracks were about two miles northeast of the fault line. (See Plate 9, Figure 11.)

(d) By far the largest and most numerous cracks were found on the mountain ridges east of the Blackburn ranch in the neighborhood of the sinks already described. From the ranch we followed up a winding ridge between two canyons. There were hundreds of cracks along the ridges—some over a foot wide. The cracks were mostly parallel to the direction of the ridges—some east and west, and some north and south. The largest cracks were found in the immediate neighborhood of the sinks. Two or three ridges which were only fifteen to twenty-five feet wide on top were all broken up—literally shaken to pieces. At a number of places the hard dried surface of the soil was broken into little patches half the size of one's hand or smaller.

In the reports received, cracks in the ground are reported at five other places, namely, Keen Camp, Hemet Dam, Idyllwild, Thomas Mountain, and Nuevo. Plate 10, Figure 13, is a photograph of one of the cracks in the region east of the Blackburn ranch.

Landslides.—A number of slides occurred in the mountains south-east of San Jacinto. The road from Hemet to Strawberry Valley was blocked in a number of places, the first serious slides being about five miles beyond Vallevista. Several persons who were spending the day in these mountains were obliged to leave their automobiles after the earthquake and walk home. Two men driving up the mountain in an automobile were swept off the road by a slide. They would have rolled down several hundred feet except for the fortunate circumstance that their car landed against a tree before the slide had carried it very far.

Many rocks and boulders were shaken from their places and rolled down the mountain sides, the larger ones destroying trees or anything else that lay in their paths. Figure 14, Plate 11, shows a granite boulder which rolled forty or fifty feet down the embankment of the San Jacinto River, and a hundred feet out into the bed of the stream. Figure 15 shows a landslide on the south side of the river in this same locality, on the Strawberry Valley road about four miles up from Vallevista.



Fig. 12. Crack in concrete road, one mile northwest of San Jacinto. Negative taken May, 1918, by F. R.

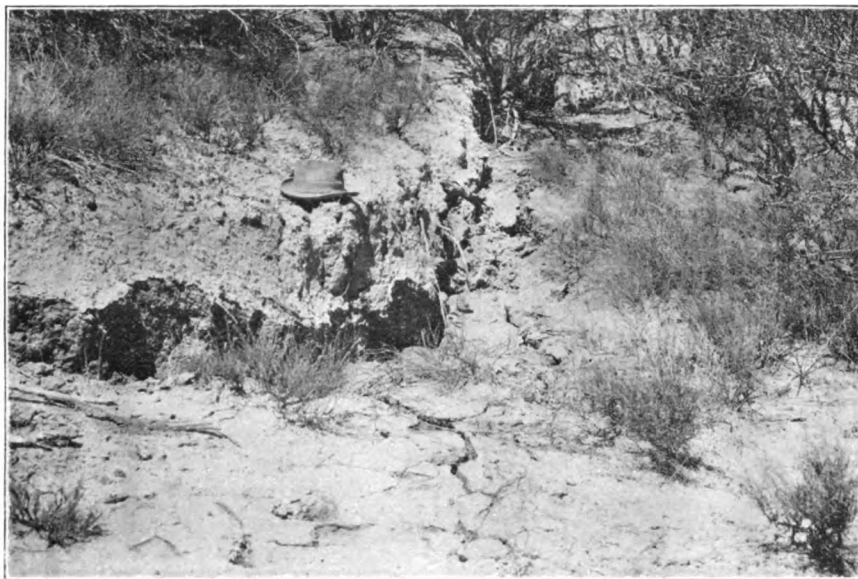


Fig. 13. Crack in ground near sunken area east of Blackburn Ranch. Negative taken April 26, 1918, by H. H.

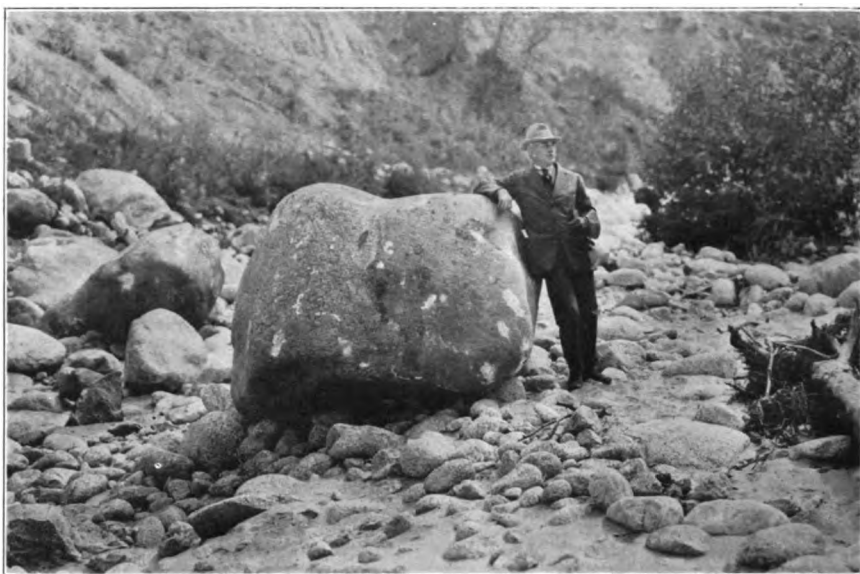


Fig. 14. San Jacinto River Canyon. Boulder dislodged from slope in the background. Negative taken April 25, 1918, by H. H.

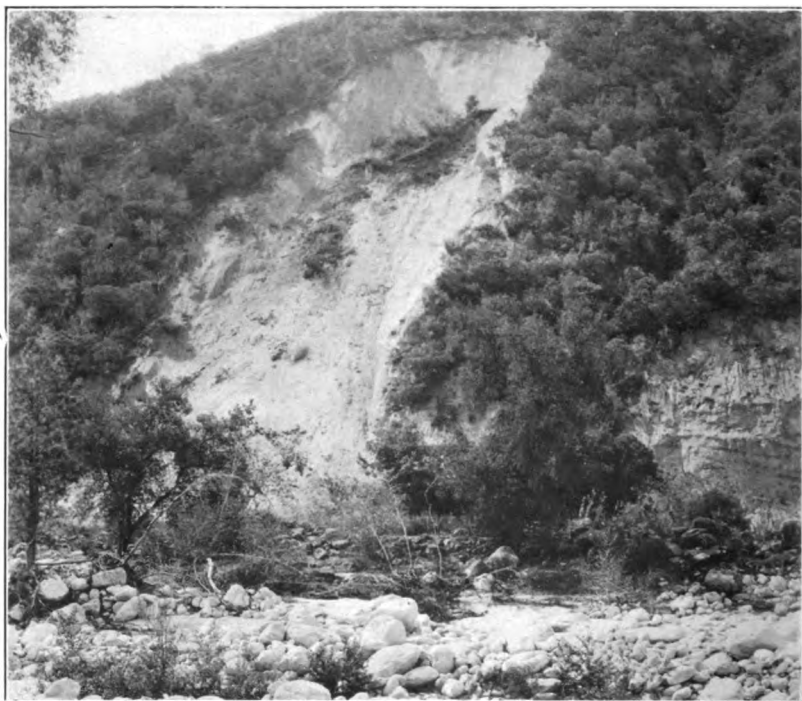


Fig. 15. Landslide on south side of San Jacinto River Canyon, about five miles southeast of Valle Vista. Negative taken April 25, 1918, by H. H.

Immediately after the earthquake great clouds of dust were seen over the mountains, due to landslides, rolling rocks, and the shaking of the dry earth. (See Plate 12, Figure 16.) This photograph was taken by Mr. P. D. Mason, and his statement of his experiences is as follows:

"The photograph of dust clouds was taken Sunday, April 21, 1918, at about 3:30 o'clock in the afternoon, at a place about three or four miles east of Cabazon. With a party of friends I was riding along on the wagon road in an automobile on the north side of the railroad, when our attention was attracted to the dust rising from the ravines and hillsides on the east side of Mt. San Jacinto, which is, I should judge, about two and one-half or three miles from where the dust was rising. The driver of the car experienced a dizzy sensation. He stopped the car and we immediately got out. As we stepped on the ground we experienced a sensation which was not unlike that of stepping on the deck of a moderately large ship, while on a rolling sea. In addition to the rolling motion, we heard, or rather felt, a grinding sensation. Immediately thereafter we heard cracking noises like those of blasting, then the rumbling noises of the rock falling down the mountain side, ending with a thud, or dead sound like that of throwing stones into thick mud, too thick to splatter. The cloud of dust came mostly from the bottom of the ravines. There seemed to be two kinds of dust, one being much lighter than the other. The lighter may have contained some smoke, which we concluded may have been produced by the friction. The dust continued to rise for some time."

The extent of the shaking of the earth may be illustrated by an occurrence which happened at the Blackburn ranch. An orchard planted in sandy soil had been cultivated a few days before the earthquake, and furrows had been plowed between the rows of trees for the purpose of carrying irrigating water. The water had not yet been turned in when the earthquake came, and after the shock the furrows were almost completely obliterated.

Sand-craters.—On the farm of A. McCleish, one mile northwest of San Jacinto, where cracks were found in the alfalfa field, we discovered also a considerable number of small sand-craters, where the water had been forced out of the soil, forming small ponds. A large number of similar craters was also found in a field on the opposite side of the road. This was low ground and probably well soaked with water used for irrigation purposes. A photograph of three craters is reproduced in Figure 17, Plate 12.

Springs.—As is usual in the case of severe earthquakes, the flow of some springs and wells was reduced, while that of others was increased. At a number of places the temperature of hot springs is reported to have changed, but no quantitative measurements were obtained. Relief Hot Springs, on the edge of the valley, four miles north, northwest of San Jacinto, was visited, and we were surprised at the apparent lightness of the shock there. No damage was done, not even to a brick building in the process of construction.

At Swoboda Spring, located between two and three miles east of San Jacinto, across San Jacinto River and at the base of the mountains, no damage was done the hotel. A water pipe was broken and a coffee pot overturned.

These two springs are probably on the fault indicated on Dr. Arnold's map as the Hot Springs Fault. The comparative lightness of the shock at the two springs just mentioned seems to show conclusively that the slip which caused the earthquake did not occur on the Hot Springs Fault.

INTENSITIES AND ISOSEISMALS

One hundred and sixty-six reports of the San Jacinto earthquake were collected by Mr. Hamlin, five were added by Messrs. Strong and Rolfe, and three by the author. The reports were studied by Mr. Rolfe and the intensity of the earthquake determined by him at each place from the data given by each observer. The observer making the report is not asked to estimate the intensity of the shock, but merely to answer questions and relate his experiences. The estimate of intensities is then made by the person who works up the reports. The writer has also studied these reports and made an independent estimate of intensity for each. The isoseismals shown in Plate 5 are the result of the combined estimates of Rolfe and Townley, but the curves have been drawn by the author without consultation with Mr. Rolfe.

The observational data are summarized in Table I. No attempt has been made to give all of the data, and the usual columns for duration and sounds have been omitted.

Some difficulty was experienced in drawing the isoseismals, but it is believed that the curves drawn represent fairly well the data at hand. Some of the reports show an increase of intensity in the neighborhood of the Colorado River, which may be explained by the nature of the ground along the river or by the occurrence of a sympathetic shock. The report from Needles is the one that it is most difficult to



Fig. 16. Dust clouds over San Jacinto Mountains. Photographed immediately after the earthquake of April 21, 1918, by P. D. Mason, from a point three or four miles east of Cabazon.



Fig. 17. Sand craters on ranch of A. McCleish, one mile northwest of San Jacinto. Negative taken April 25, 1918, by S. D. T.

TABLE I. SAN JACINTO EARTHQUAKE, CALIFORNIA, APRIL 21, 1918.

Place	Latitude N.	Longitude W.	Number of Reports	Intensity	Number of Shocks	Remarks
Acton	34°28'	118°12'	1	5	1	
Aguanga	33 27	116 52	2	7	3, 5 or 6	Many boulders rolled down mountains.
Alhambra	34 6	118 8	1	6	1	Three maxima.
Alamitos Bay.....	33 46	118 6	1	6	3	Three distinct shocks.
Amboy	34 34	115 45	1	6	1	
Anaheim	33 50	117 55	2	7	3, 1	Great difference in two reports.
Avalon	33 20	118 20	1	5+	3	No underground sounds.
Azusa	34 8	117 54	1	4	1	
Barstow	34 54	117 1	1	5	1	
Reaumont	33 56	116 59	2	7+	3, 3	
Beverly Hills.....	34 5	118 25	1	5	1	
Blackburn Ranch	33 41	116 51	1	9+	—	
Blythe	33 35	114 41	1	5+	2	
Brawley	32 59	115 33	2	5	1, 1	Automobiles in street moved back and forth 1 to 2 feet.
Brown	35 47	117 55	1	4+	1	
Cabazon	33 55	116 47	1	8	2	Two large railroad water tanks de- stroyed.
Calexico	32 40	115 31	2	5	1, 2	Automobile surged back and forth for 2 minutes.
Calipatria	33 8	115 30	1	6	1	
Camp Baldy.....	34 15	117 40	2	5+	2, 2	Twelve miles north of Upland.
Campo	32 36	116 30	1	5	1	
Carpinteria	34 25	119 31	1	4+	1	
Chatsworth	34 15	118 37	1	5	1	
Claremont	34 6	117 43	1	5+	1	
Coachella	33 43	116 11	2	7	1, 3	Great clouds of dust over mountains. Two picnickers injured by rolling rocks.
Coahuila	33 32	116 44	1	7+	4	
Colton	34 4	117 20	1	5	1	
Compton	33 54	118 13	1	6	2	
Cornell	34 7	118 47	1	4+	1	Fifty miles northeast Los Angeles.
Corona	33 53	117 35	1	7	2	
De Luz.....	33 27	117 21	1	7	—	Twelve or 14 shocks in 2 or 3 days.
Descanso	32 51	116 38	1	5+	1	
Domino	34 54	118 27	2	5	2, 2	
Dove Springs.....	35 26	118 1	1	4+	1	Thirty-two miles north of Mojave.
El Cajon.....	32 47	116 58	1	5	1	
El Modeno.....	33 47	117 48	1	6	2	
Elsinore	33 40	117 20	1	6	—	
Emedio	35 3	119 1	1	5	2	

TABLE I. SAN JACINTO EARTHQUAKE, CALIFORNIA, APRIL 21, 1918.—*Continued.*

Place	Latitude N.	Longitude W.	Number of Reports	Intensity	Number of Shocks	Remarks
Encinitas	33° 3'	117° 18'	1	5	2	
Escondido	33 6	117 6	2	5	2, 2	
Fairmont	34 44	118 25	1	5	3	
Fallbrook	33 23	117 15	1	6+	1	Ground seemed to roll like waves.
Forest Home.....	34 6	116 53	1	6	1	Fifteen miles east of Mentone.
Fullerton	33 52	117 54	1	6	—	
Goff's	34 56	115 4	1	6	1	
Gorman	34 48	118 51	2	4+	1, 1	
Heber	32 43	115 32	1	5	1	
Hemet	33 45	116 58	3	9	1, 3, 2	Partial destruction of buildings. One ob- server reports 3 very distinct shocks.
Hemet Dam.....	33 40	116 42	1	7+	—	Small fissures in ground. Dust cloud's over mountains.
Huntington Beach	33 40	118 0	1	6	2	Two shocks or two peaks of one shock.
Idyllwild	33 45	116 43	1	8+	many	Light cracks all over.
Imperial	32 51	115 35	1	5	1	
Jaw Bone Canyon..	35 19	118 3	1	4	1	
Keen Camp	33 45	116 45	2	7+	1, many	One observer reports cracks in ground.
Kramer	34 59	117 35	1	4+	2	
Laguna Beach.....	33 32	117 47	1	6	1	Duration 1 min. 31 sec.
La Jolla.....	32 51	117 17	1	4+	1	
Lebec	34 50	118 51	1	4+	2	
Long Beach.....	33 46	118 11	1	5	several	
Los Alamitos.....	33 48	118 5	1	7	2	
Los Angeles.....	34 3	118 15	25	5.5	—	
Los Olivos.....	34 40	120 6	1	3	2	
Ludlow	34 43	116 10	1	5+	2	
Mecca	33 34	116 5	1	6+	—	
Mesa Grande.....	33 10	116 46	1	6	2	Loud roaring before shock.
Mojave	35 3	118 11	1	4+	1	Observer 17 miles north of Mojave.
Monrovia	34 8	118 00	1	6	1	
Mt. Lowe.....	34 13	118 8	1	4+	3	
Mt. Wilson.....	34 13	118 4	1	5	2	
National City.....	32 40	117 5	1	6	2	
Needles	34 50	114 36	1	7+	1	
Newhall	34 23	118 31	2	4	1, 1	One shock with slow- ing up at middle.
Nuevo	33 50	117 7	1	8	6 or 8	Fissures in ground.
Oceanside	33 12	117 23	1	6	2	
Ogilby	32 49	114 50	1	5	1	
Ojai	34 25	119 12	1	5	1	
Ontario	34 4	117 39	1	4+	1	
Oxnard	34 12	119 11	1	4	1	

TABLE I. SAN JACINTO EARTHQUAKE, CALIFORNIA, APRIL 21, 1918.—*Concluded.*

Place	Latitude N.	Longitude W.	Number of Reports	Intensity	Number of Shocks	Remarks
Palo Verde.....	33° 26'	114° 44'	1	6	1	Man under floor of building reported sounds "like a giant bowling alley when the ball hits the pins."
Palmdale	34 35	118 7	1	6	1	
Palm Springs	33 49	116 33	2	7	1, 1	
Pasadena	34 9	118 9	1	4	1	
Perris	33 47	117 14	2	7+	1, —	
Picacho	33 1	114 35	1	3	—	Three separate shocks.
Pine Knot	34 15	116 53	1	6+	3	
Point Loma.....	32 43	117 15	1	6	—	
Pomona	34 3	117 45	3	6.5	1, 2, 2	
Pot Holes.....	32 50	114 29	1	5	2	
Redlands	34 4	117 11	1	7+	—	Some chimneys shaken down.
Rialto	34 6	117 22	1	6	1	
Roosevelt	34 40	118 27	1	5	1	
San Bernardino ..	34 6	117 17	3	6.5	1, 1, 2	
San Diego.....	32 43	117 10	3	5	1, —, —	
San Fernando.....	34 17	118 26	2	5+	1, 1	Two distinct series of shocks.
San Gabriel.....	34 5	118 6	1	6	2	
San Jacinto.....	33 47	116 58	2	9+	15, 1	
S'n Juan Capistrano	33 30	117 40	1	6+	3	
San Onofre.....	33 23	117 34	1	6	many	
Santa Ana.....	33 45	117 53	2	5+	1, 1	Person laying hose on lawn did not feel shock.
Santa Barbara.....	34 25	119 42	2	5	4, 2	
Santa Monica.....	34 1	118 30	1	5	15 to 20	
Saticoy	34 17	119 9	1	4+	2	
Saugus	34 24	118 32	4	5+	3, 1, 1	
Seven Oaks.....	34 5	117 12	1	6+	3 or 4	Standing automobiles moved back and forth
Taft	35 10	119 26	1	3	1	
Thomas Mountain	33 37	116 41	1	8+	2	
Triunfo	34 9	118 9	1	4	3	
Tustin	33 44	117 49	1	5	1	
Venice	34 00	118 30	1	5+	3 to 4	Another observer did not feel shock.
Ventura	34 17	119 17	1	5+	—	
Victorville	34 32	117 18	1	6+	3	
Voltaire	34 43	118 32	1	6	4	
Warner Springs ..	33 17	116 37	1	7	—	
Westminster	33 45	118 0	1	6	2	Three shocks in close succession.
Wildomar	33 36	117 16	1	7+	3	
Wister	33 18	115 40	1	6	1	
Yucaipa	34 5	117 5	1	6	4	
Yuma	32 43	114 37	1	3	1	

harmonize with the curves as drawn. Our estimate of intensity from the single report at hand is VII +. Besides the minor effects of swaying of buildings, rattling of dishes, etc., there were reported falling of plaster and chimneys and cracking of walls. The Weather Bureau published no report from Needles, but there are several reports from places in Arizona to the north and east of Needles which do not have nearly so high intensities. These are Mohave City V, Oatman V, Yucca IV, Kingman IV. These places are from twenty to forty miles from Needles.

TIME AND DURATION

In the reports received the time of the occurrence of this shock is reported from 3:05 to 4:30, the last probably in error by an hour. Fully ninety per cent of the times lie between 3:30 and 3:35. Apparently none of the times of beginning of the shock have been determined with astronomical accuracy. There is a great range in the reported duration of the shock or shocks. Some evidently have reported the duration of the main shock while others have included at least some of the aftershocks. The durations reported range from two seconds to ten minutes, with an average value of forty-seven seconds. Most of these of course are mere estimates and it is well known that only a very few people are able to estimate a short time interval in a way which even roughly approaches scientific accuracy.

Two observers determined the duration by their watches. Thomas A. ———, at Laguna Beach, was eating lunch at the time of the earthquake, and writes as follows: "I did not rise during shock, but held on to the table. The moment the shock started I pulled out my watch and caught the exact duration of shock, which was one minute and thirty-one seconds." A. P. Wiley observed the duration at Palo Verde to be one minute, ten seconds. Lesser vibration undoubtedly continued for much longer than this. Mr. Frank S. Hewitt reported from Calipatria as follows: "An engineer out in the field was running a level at the time and informed me that by the spirit level the earth did not settle for about fifteen minutes."

DIRECTION

The questionnaire used by Mr. Hamlin does not ask for any information concerning the direction in which the earthquake waves travel, for the reason that it has been found by experience that data

of this kind are not trustworthy. This point has been considered by Dr. Branner and others in preceding numbers of the BULLETIN.²

There are two reports, however, which give valuable information on this point. Mr. T. A. Miller, agent of the Santa Fe Railway at Goff's (about thirty miles west of Needles), reports as follows: "I had advice of the approaching earthquake several seconds before it actually occurred at this particular point, and was expecting and waiting for the shock. I was working on the train dispatcher's phone at 3:33 p.m. when I heard the operators at Newberry and Hector cry out that they were having an earthquake, that the building was rocking, and there was great disturbance. It must have been fully four or five seconds after this that I felt the shock approaching. In fact, it was so long afterwards that I thought we would not feel it. Newberry and Hector are about 100 miles west of this place. This experience plainly shows the shock traveled from west to east and was about four seconds coming that distance."

In a straight line, Newberry is seventy-five miles, Hector seventy-seven miles and Goff's 135 miles from San Jacinto. If we assume the origin of the disturbance to have been at San Jacinto, then the waves would reach Newberry and Hector at practically the same time, and this seems to have been the case. As Goff's is some sixty miles further from San Jacinto than the other two places, the disturbance would not reach there until some time later. Using four seconds, Mr. Miller's estimate of this time, we obtain a speed of 15 miles per second for the rate of propagation of the earth waves. This value is more than twice the known speed of propagation. This discrepancy may be explained in one of three ways. First, that the origin of the shock was not at San Jacinto; second, that the disturbances felt at Newberry and Hector and at Goff's did not originate at the same place; and third, that the observer underestimated the time. The last explanation seems the most probable. Except for the high intensity at Needles, we have no evidence that there was more than one origin of shocks. If there was a sympathetic shock near Needles, simultaneous with the shock at San Jacinto, then the disturbance would have been felt at Goff's before it was at Newberry and Hector, which is contrary to the facts. Of course, the sympathetic shock might have occurred after the main shock, but there is no evidence to support such a theory.

² *Bulletin Scismological Society of America*, 4, 26.

An aftershock at 4:02 p.m. was reported by Mr. E. W. Tuttle, telegraph operator at Wister. The same shock was felt by the operator at Salton, between twenty-five and thirty miles northwest of Wister. The waves traveled in a general southerly direction, as may be seen from the following extract from Mr. Tuttle's letter: "The second shock, which occurred at 4:02 p.m., was very slight, being only a trembling. Agent at Salton called me about 4:01 $\frac{3}{4}$ p.m. and asked me if I had felt that shock that had just 'hit.' Said it hit him at 4 p.m. sharp. Just as he asked me I felt it."

SOUNDS

A study of the answers to the questions concerning "underground sounds" does not disclose any exceptional information. Thirty-seven per cent of the observers report having heard underground sounds either before, with or after the shock. Forty-nine per cent report that they did not hear any such sounds and fourteen per cent make no answer to the question—therefore negative by implication. These sounds are variously described as rumbling or roaring, faint or loud, etc. As is usual the sounds were heard by some people and not by others. A study of the geographical distribution of the places at which sounds were heard shows that they were not confined to any particular part of the area affected by the shock. Of the twenty-five observers in Los Angeles twenty-eight per cent reported underground sounds, sixty per cent reported none, and twelve per cent made no answer to the question.

At the Blackburn ranch, the observers reported that the sounds preceded the shock and all of the aftershocks, so that they always had warning of a shock before it was felt.

AREA AFFECTED

Taft, in Kern County, is the most northerly station from which Mr. Hamlin's observers reported the earthquake having been felt. The most easterly station was Seligman, Arizona, according to the U. S. Weather Bureau reports. The most southerly station from which a report was received was Campo, in San Diego County, near the Mexican boundary, but as the intensity was V at this place it is certain that the region of the sensible shock extended into Lower California. The most westerly station from which a positive report was received was Los Olivos.

Negative reports were received from Ozena, twenty-eight miles northeast of Santa Barbara; from Wheeler Springs, seventeen miles north of Ventura; and from Newberry Park, forty miles northwest of Los Angeles, where a party of four persons were sitting on the ground and the shock was not felt by any of them. Two reports were received from Taft; one observer felt the shock and the other did not. The U. S. Weather Bureau reports the shock as having been felt in Fresno, which is over one hundred miles further north than Taft, the most northerly place from which Mr. Hamlin's reports were received.

It does not seem possible to make an accurate estimate of the area over which the shock was felt. If we describe a circle with San Jacinto at the center, and Fresno on the circumference, we shall include an area of over 200,000 square miles, taking in large sections of California, Nevada, Arizona, Mexico, and the Pacific Ocean, from which no reports whatever have been received. If we describe a circle with San Jacinto as the center, and Los Olivos on the circumference, we shall include all of the territory covered by Mr. Hamlin's reports, and also the northern part of Lower California, a section of the Pacific Ocean, and a considerable desert region north of the Santa Fe Railway, from which no reports were received. On the other hand, this circle will not include all of western Arizona from which reports were received by the Weather Bureau. This circle has an area of about 110,000 square miles, and is, I believe, a fair estimate of the region over which the shock was felt.

INSTRUMENTAL RECORDS

This earthquake was of sufficient intensity to be recorded by seismographs in all parts of the world. Thus far reports have been received from Cambridge, Denver, Ottawa, Point Loma, and Washington, in North America; La Paz, Bolivia; Barcelona, Spain; Coimbra, Portugal; Zi-Ka-Wei, China, and Manila, P. I.

Taking those stations for which Δ , the distance of the station from the epicenter is given, and computing O , the time at which the earthquake occurred, by means of Table I, of Dr. Klotz's seismological tables,³ we have the following tabulation:

³ Publications of the Dominion Observatory, Ottawa, 3, No. 2.

Station	Δ km.	O
Barcelona	9640	22 ^h 32 ^m 38 ^s G.M.T.
Cambridge	4040	24
Coimbra	9100	22
La Paz	7660	34
Ottawa	3600	24
Washington	3535	22 32 20
Mean		22 32 27

Taking all of the places except La Paz, the stereographic projection tables, No. 14, were used for locating the epicenter. The method gives a system of intersecting circles, but the places all lie in the same general direction from the epicenter, so the circumferences of the circles are too nearly parallel to give accurate results. All of the points of intersection, however, fall within a circle of 6 mm. radius, the radius of the projection circle being 10 cm. The mean point of intersection gives 116° west longitude and 33° north latitude for the coördinates of the epicenter. This is not in very good agreement with the results of field investigations, but, as stated above, the data are not such as to give a determinate solution of the problem.

AFTERSHOCKS

A large number of aftershocks was felt at San Jacinto, Hemet and the regions near these places. So far as known, no one kept an accurate record of the shocks. The high school cadets guarded the damaged property in Hemet during the night following the earthquake, and one cadet is reported to have felt twenty-seven shocks between 7:30 p.m. and 7:30 a.m. At the Blackburn ranch, Mr. Blackburn reported that he began counting shocks after retiring on the evening following the earthquake, and counted nineteen shocks in the short space of time before he went to sleep, and that he counted seven more the next morning in the short interval between the time he awoke and when he was ready to leave the house.

One observer reported that aftershocks were felt frequently up to May 5th. Three shocks were felt by the writer while in Hemet, as follows:

1918 April 24, 8:23 p.m. Intensity, IV.

April 26, 5:03 a.m. Intensity, III.

April 26, 7:05 a.m. Intensity, II.

(The above times are seven hours slow of Greenwich.)

HISTORICAL

On December 25, 1899, at 4:25 a.m., a severe earthquake was experienced at San Jacinto and many brick buildings were partially wrecked. From the account of Mr. Claypole,⁴ I gather that none of the buildings were completely wrecked, but that the second stories of all the brick buildings were badly damaged. Many of these buildings were patched up after this shock, and that is probably one reason why they did not stand up better when the shock of April last came.

The testimony of persons who experienced both earthquakes is that they were of about the same intensity. In 1899, as well as in 1918, the intensity at Needles was very marked. Mr. Claypole quotes a report from Needles as follows: "A terrific shock of earthquake at 4:35 a.m. lasted fully thirty seconds, stopping all clocks. It broke glass and gave the town a thorough shaking. The vibration was from northeast to southwest." It should be noted that the time given in this report is ten minutes later than the time for San Jacinto.

The following abstract of newspaper accounts of the 1899 shock has been kindly furnished by Professor Harry Fielding Reid, of Johns Hopkins University:

"A severe earthquake occurred about 4:25 a.m., P.S.T., December 25, 1899, in the neighborhood of San Jacinto, California, and lasted from one to two minutes. The damage seems to have been limited to the neighborhood of San Jacinto and Hemet, the property loss being from forty to fifty thousand dollars. Brick buildings suffered most, nearly all of them being severely damaged. Frame buildings were not much affected, but furniture in them was overthrown. Walls of the county hospital were very badly damaged. The Highland asylum at Gables was cracked and its chimney shaken down. At Hemet, walls were overthrown or cracked and only two chimneys remained standing. Falling adobe walls at Soboba killed six Indians and wounded eight others. The earthquake was the severest ever felt at Riverside; some brick buildings were cracked and some chimneys overthrown. At San Bernardino, goods were shaken from the shelves. At Los Angeles, people were frightened and rushed into the street, but no damage seems to have been done. The shock was felt from San Diego to Seligman, Arizona. In the neighborhood of the origin, artesian wells flowed more freely after the shock, and two hot sulphur geysers are reported to have burst forth near Hemet. About

⁴ E. W. Claypole, *American Geologist*, 25, 106 and 192, February, 1900.

ten miles west of the town of San Jacinto, in the low hills near the extinct volcano of that name, land about a square mile in area sunk from thirty to one hundred feet and was greatly broken up by many deep and wide cracks. The sinking seems to have been progressive, continuing for two or three months, and not to have occurred at once.

"Thirty shocks were reported on December 25th and others on the following day. A later shock occurred March 18, 1900."

From the accounts, Dr. Reid estimates that the shock was felt over an area of 150,000 to 180,000 square miles. Mr. Claypole, who was in Pasadena at the time of the shock, and who visited San Jacinto a few days afterward, makes no mention of the sinking lands or of hot sulphur geysers. The intensities of the two shocks at San Jacinto, San Bernardino, Los Angeles and Needles, and the area over which they were felt, are almost identical, and the shock of 1918 seems to have been almost an exact repetition of that of 1899.

CONCLUSIONS

The investigations of the earthquake of April 21, 1918, show, and I think conclusively, that the shock was caused by a slip along the San Jacinto fault. No certain surface indications of this slip were found, but the hypocenter was probably not located at a very great depth, as the intensities at San Jacinto and vicinity were much greater than at any other place. The region of maximum intensity extended from about one mile northwest of San Jacinto to the region east of the Blackburn ranch in the Bautista Canyon, and possibly further—a total length of at least ten miles. There is some evidence, although I think not conclusive, tending to show that the intensity was greater near the extremities of this line than at intermediate parts. Some observers report two distinct maxima, which would seem to indicate that this was a twin earthquake, but a study of the distribution of the places where the shock was felt as single and as double does not reveal any proof of this. Others reported three shocks or three maxima, and it should, I think, be considered a complex earthquake, resulting from movement along the fault plane of several miles in extent.

THE EARTHQUAKE OF APRIL 21, 1918, IN THE SAN JACINTO MOUNTAINS

BY FRANK ROLFE AND A. M. STRONG

Investigations made immediately after the earthquake of April 21, 1918, in the San Jacinto Valley, California, made certain that the cause was a disturbance along the San Jacinto fault. The location of this fault has been described in considerable detail by Carl H. Beal in BULLETIN No. 3, Vol. 5, OF THE SEISMOLOGICAL SOCIETY OF AMERICA, starting with its junction with the San Andreas fault near San Bernardino and extending in a southeasterly direction into Mexico. The purpose of the trip described in this paper was to examine the country along the fault in the mountain area southeast of the San Jacinto Valley, and to procure data of the intensity of the shock in the mountain valleys to the east and west of the fault line. Traveling was done by automobile with short side trips on foot to points along the fault.

The first stop was made at the Blackburn Ranch on Bautiste Creek, about eight miles southeast of Hemet. The fault is located in the hills about one and one-half miles to the east of the ranch house. The formation here is soft sandstone and shale, probably deposited in shallow lakes or possibly old valley fills, and the effect of the shock in cracking and generally shaking up the ground is very noticeable. This locality had been examined in detail by S. D. Townley and Homer Hamlin.

The general line of the fault from the Blackburn Ranch is southeast, roughly paralleling Bautiste Creek. As the road along this stream was not passable for an automobile, we took the main road south from Hemet, across the Saint John's grade, Lewis Creek and Wilson Creek Valleys, and into the Coahuila and Terwilliger Valleys just west of the fault line. This route took us some ten miles to the west of the fault. No signs of rock falls or other disturbance were visible along this road.

The shock was quite severe in the Coahuila and Terwilliger Valleys. Two stone houses and one adobe house were thrown down, and a number of chimneys were toppled over. At the Del Ollias store, near the old Coahuila Indian Reservation buildings, we were informed that practically everything was thrown off the shelves and that ground

waves could be seen on the valley floor. In reporting to the U. S. Weather Bureau, the keeper of the store estimated the intensity as IX. The fault here is on the east side of the valley, along the slope of Thomas Mountain, over which the shock raised a cloud of dust described as being like a fog. Some rocks are said to have been shaken loose, and a light cloud of dust raised over Coahuila Peak to the northwest. The hot sulphur spring on the Indian Reservation has increased both in flow and temperature since the severe shock of April 21, 1918.

From a point in the road at the head of Bautiste Creek we went on foot to Hog Lake. The route followed was up a narrow ridge, soil covered but containing a large number of loose granite boulders from a few inches up to two feet in diameter. At a point about a mile southwest of Hog Lake we found a strip of ground about 300 feet in width on which every loose rock had been moved along the surface of the ground. On the surface of the ridge many of the rocks were overturned or rolled some distance down the hill; on the top they had been shifted from two to six inches in a direction parallel to the ridge fault and at right angles to the axis of the ridge.

Hog Lake is a small pond in a long, narrow, marshy sag on the west side of Thomas Mountain, showing all the marks of a sink along a fault line. The moist ground on the east side of the lake was cracked in several places, the largest crack being about six inches wide. In the sloping, marshy meadow to the south of the pond an area of about a quarter of an acre had settled at some time before this shock, according to the statement of one of the settlers. The cracks and the spalling of the banks to vertical faces, at one point six feet high, seemed recent.

It is about nine miles from Hog Lake to the shattered ground to the east of the Blackburn Ranch, part of the country being in granite and part in sandstone formations. The line of the fault northwest of Hog Lake is not plainly shown by the topography, but reported rock slides in the canyons to the northwest indicate its location. Southeast of Hog Lake the general line of the fault is plainly shown as a bench forming the foot of Thomas Mountain. Several springs, of which we were told but did not visit, probably mark its location. A settler who was at the springs at the time of the shock of April 21, 1918, reported that he was knocked down and the "red shank brush" on the hillsides shaken until it looked as if it would be pulled out by the roots.

The road from Terwilliger Valley to Hemet Lake Valley crosses the fault near the foot of the Hamilton grade, some six miles southeast of Hog Lake. At this point we found a small gravel knoll, opposite

the mouth of Hamilton grade, to be badly shattered. Hamilton Creek Canyon is a narrow canyon about one and one-half miles long. It has been cut or broken through granite rock along the line of the fault. A few small rock slides and fallen boulders were the only signs of the recent shock that we observed along its course. At the upper end the canyon opens out into a flat basin of sandstone known as Burnt Valley. On the west side of the creek, just where it enters the valley, there is a spring in a narrow trough on the side of the hill. This trough is several hundred yards in length and water seems to come up all along it, as the bottom is sodded over for a width of fifty feet or more. This is undoubtedly another old sink similar to Hog Lake, but smaller; there were no signs of recent ground movement.

The intensity of the shock of April 18, 1918, in the eastern part of the Terwilliger Valley may be judged from the following information obtained from a settler in Sec. 12, 8 S., 3 E. A small, well-built chimney was set about two feet out of line but not overturned or broken. A poorly built stone fireplace and chimney were wrecked. Dishes were thrown from shelves, milk thrown out of pans, and a small water tank half emptied by the water splashing out.

Leaving this locality, we crossed the Hamilton grade into the southerly end of the Hemet Lake Valley. At Kenworthy the shock of April 18, 1918, was heavy. Everything on shelves was thrown off; the light frame buildings were racked but not damaged; men working under a wagon were unable to get to their feet; clouds of dust formed over the mountains on both sides of the valley, that over Thomas Mountain being the heaviest; a large nearby spring increased its flow.

Our last visit to the fault line was at the head of Horse Canyon, four miles in an air line from the sink on Hamilton Creek. On the trip down the canyon the only signs of the shock were a few displaced boulders. The volume of the small streams seemed to have been increased, a fact which we attributed to the recent shock, although we had no other data to verify this conclusion.

Expecting to find the fault on the west side of the main canyon, we examined it with field glasses, but failed to find anything in the topography indicating its exact location. The bottom of the main canyon and the west side is granite; the east side, extending up into Vandeventer Flats, is sandstone. We returned up a narrow sandstone ridge, the top of which we found to be shattered and cracked in much the same way as the ridges near Blackburn ranch. This place is one

and three-quarters miles to the east of the line of the fault as determined by Hog Lake and Hamilton Creek. This point was as far south as we could get on this side of the mountains. We returned by Hemet Lake and Strawberry Valleys, and Strawberry grade to Hemet, the route taking us from four to six miles east of the fault line.

At Hemet Lake the caretaker told us that no damage had been done to the high masonry dam at that place—not even a crack in the plastering. Although the shock at this place was severe, neither the caretaker nor his wife, both of whom were looking at the lake when it occurred, observed any wave action on its surface. Cracks appeared in the moist ground, and a large spring dried up; the flow of the spring, however, is gradually coming back.

At Keen Camp the shock was severe, but the only damage was the cracking of rubble chimneys. In Strawberry Valley a good deal of damage was done by the falling of chimneys and foundation walls, due largely to the character of the mortar in which the rubble was laid. All the trails around San Jacinto and Tahquitz Peaks and the mountain roads were damaged by rock falls and the cracking of the fills on the outer edges. Dead limbs were shaken from trees. After the big shock fine cracks were found in the ground, but they had filled with dust before our arrival,—about three weeks after the shock.

Throughout the entire district visited the aftershocks had been noticeable, and we experienced slight rumblings and shocks two weeks after the first heavy shock. We spoke with several persons who had felt, in nearly the same spot, the heavy shocks of 1918 and 1899. Some reported that of the earlier date the greater; others thought it not so great as the latter date; all agreed that there was not much difference in the intensities of the two shocks. The conditions at Blackburn Ranch and at Hog Lake indicate that there was a greater ground movement in 1899 than in 1918.

We found no evidence of actual displacement along the fault due to shocks of recent date. While the location of the old fault plane is evident near Hog Lake and Hamilton Creek, at other places all signs of it have disappeared. At a number of places in the district examined the fault passes under slightly tilted beds of sandstone and shale. Our limited observations failed to show any signs of displacement in these beds, whose deposition probably followed the period of great activity of the fault. The most noticeable effects of the shock along the general line of the fault were found on the tops of narrow ridges, seen in three

different places, the course of the ridge in each case running about at right angles to the fault line. These areas were comparatively small and they did not seem to be necessarily on the direct line of the fault.

All observers reported that the shock caused clouds of dust to rise along the sides of the hills and canyons; we found no signs of large rock slides or marked displacements to cause this phenomenon, which seemed likely to be due to a general shifting and cracking of the ground surface, and was more evident in the territory to the east of the fault. Rumbling sounds seemed to have accompanied many of the shocks. In general there was nothing to indicate that the shock was more severe in the mountain area to the southeast of the San Jacinto Valley than in the valley itself.

Acknowledgment is due to Mr. M. M. Hays for assistance on the trip; to Dr. Ralph Arnold and Mr. Homer Hamlin for advice and coöperation. Dr. Arnold also placed his automobile at our disposal. The residents of the section visited received us kindly and freely gave us much information about the shock. Owing to the limited time and the unfavorable weather, our examination of the country was not as complete as we desired.

TOPOGRAPHY AND FAULT SYSTEM OF THE REGION OF THE SAN JACINTO EARTHQUAKE

By RALPH ARNOLD

LOCATION AND TOPOGRAPHY

The region most affected by the earthquake of April 21, 1918, is included in the same belt of faulting and disturbance as that embracing the territory of maximum shock of the earthquake of June 22, 1915. This belt is 175 miles long and extends from the eastern end of the San Gabriel Mountains in a southeasterly direction along the southwestern flank of the San Jacinto Range, out into the southern end of the Imperial Valley, and thence for an unknown distance beyond the international boundary into Lower California. It includes the eastern end of the Cucamonga Valley, the San Bernardino, San Jacinto, Terwilliger and San Felipe valleys and the drainage areas of San Jacinto River, Bautiste Creek and Horse Canyon. The northern end of the region may be reached from the San Jacinto branch of the Santa Fe Railway; the southern part by automobile road from San Jacinto, San Diego, or the towns in southern Imperial Valley.

For the earthquake of April 21, 1918, the region of maximum disturbance was confined almost wholly to that part of the belt lying within the San Jacinto quadrangle and extending from the northwestern end of the San Jacinto Valley to Horse Canyon, east of the Terwilliger Valley, while for the catastrophe of June 22, 1915, the epicentrum was farther south, between El Centro and Calexico. The region of greatest disturbance in the 1918 earthquake is the one principally discussed in the present paper.

The San Jacinto Valley, topographically speaking, is long and flat-bottomed, and lies at an elevation of between 1400 and 1500 feet above sea level at the western foot of the San Jacinto Mountains. Its northwestern half is narrow and parallel-sided, its southern part expanded toward the southwest. The northeastern limit of the valley is practically a straight line running 47° east of south along the base of the mountains. The valley is terminated on the northwest by the range, lying south of the San Bernardino Valley, which in-

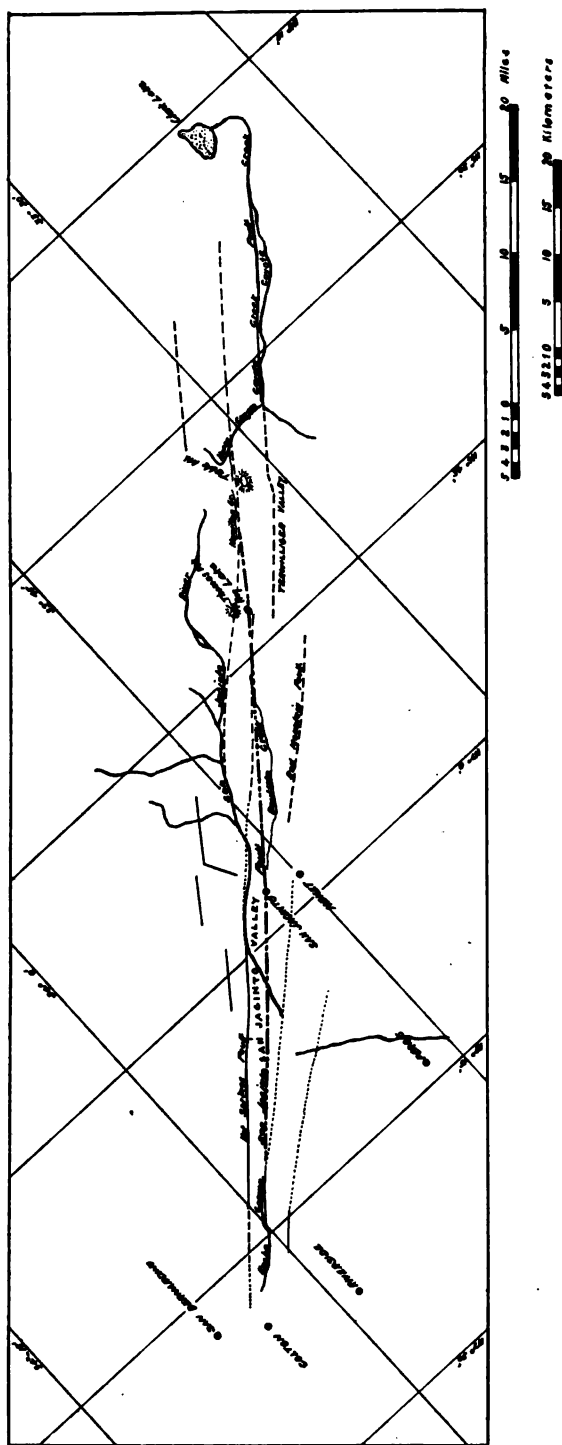


Fig. 1. Map of the San Jacinto fault zone, San Bernardino, Riverside, San Diego and Imperial counties, California. Location of main San Jacinto fault from Reche Canyon to Horse Canyon by Homer Hamlin, Frank Rolfe, A. M. Strong and S. D. Townley. Other geology and topography by Robert T. Hill.

cludes the Box Springs Mountains. The units of this range show the characteristic relief of the granitic rocks of which they are composed. According to Hill, the San Jacinto Valley is flanked on the northeast largely by characteristic bad lands topography. The southwestern edge of the valley is determined by several more or less isolated ridges and groups of granitic hills.

From the southeastern end of the San Jacinto Valley the zone of maximum disturbance follows the high ridge between Bautiste Creek and the South Fork of the San Jacinto River, thence along the southwestern flank of Thomas Mountain (elevation 6823 feet) and the northeastern border of the elevated and westerly-sloping Terwiliger Valley, and so on into the mountainous region at the head of Horse Canyon. From here it passes southeastward, across an elevated mesa and then downward into the low valley extensions of what Hill calls the San Felipe Embayment, which lies at about sea level. For practically the entire distance southeastward from the San Jacinto Valley the region is barren and uninhabited, so that records of disturbances throughout its extent must be obtained largely through the more or less isolated but lasting surface evidence produced by the earthquakes.

GEOLOGY AND STRUCTURE

The geologic discussion in this paper is based on the field work of Messrs. Robert T. Hill, S. D. Townley, Homer Hamlin, Frank Rolfe, and A. M. Strong. Through the courtesy of Dr. George Otis Smith, Director of the U. S. Geological Survey, that part of the manuscript and map of Hill's "Geography and Geology of Southern California" now being published by the Survey as a "Professional Paper," was made available to the writer. Most of the statements regarding the distribution of the surface formations and the mapping and distribution of the faults, with the exception of the location of the main San Jacinto fault, are taken from Hill's paper. Use has also been made of the information contained in Beal's¹ description of the June 22, 1915, earthquake throughout this same region.

In many regions the character of the formations takes precedence in point of interest over the structural relations of the rocks. Here it seems to the writer that the reverse condition is true, as the structure absolutely dominates the situation.

¹Beal, Carl H. The Earthquake in the Imperial Valley, California, June 22, 1915. *Bulletin of the Seismological Society of America*, 5, 130-149, September, 1915.

The rocks of most of the territory covered are chiefly crystalline schists, gneisses and granites, but immediately adjacent to the disturbed belt blocks of Tertiary sedimentaries have been faulted into the crystallines in a most abrupt manner.

The dominant structural feature of the region under discussion is the San Jacinto fault zone, which consists of one or more lines of displacement extending from the San Bernardino Valley in a southeasterly direction beyond the Mexican boundary. The zone is an offshoot of the Great Fault Belt, which extends from Point Arena to San Geronio Pass, and, to be more exact, is the southeastward extension of the Lytle Creek fault which is mapped and described by Hill.

The main San Jacinto fault as traced by Hamlin, Townley, Strong, and Rolfe, and shown on the map by a heavy line, passes out of the San Bernardino Valley through Reche Canyon, southeast of Colton, thence southeasterly down through the center of the San Jacinto Valley, probably coincident with the main road from Casa Loma, on through the center of the town of San Jacinto, thence up the small canyon which begins about one and one-quarter miles southeast of the village of Vallevista, on into the hills through the escarpment at the head of the canyon east of Blackburn Ranch, thence through the headwaters of Horse Creek (an eastern branch of Bautiste Creek), thence through Hog Lake, up Hamilton Creek, through the very pronounced fault topography at the spring west of Burnt Valley, passing Table Mountain on the northeast, and, finally, across into the region of the headwaters of Horse Canyon. From Horse Canyon the fault, according to Hill, passes southeastward through the table land northeast of Coyote Creek, and eventually loses its identity under the valley filling northwest of Clark Lake.

It seems to the writer that the evidence suggesting the presence of this fault through the middle of the San Jacinto Valley is good, as it would, in a measure, account for the topography of Park Hill, northeast of Hemet, and the unusual disturbances through the middle of the San Jacinto Valley itself during the earthquake of April 21, 1918.

According to Hill, the main San Jacinto Fault leaves the San Bernardino Valley and passes into the hills through a small canyon just south of Mound City, three and one-half miles east of Colton, and is distinctly traceable along the northeastern edge of the San

Jacinto Valley to a point east of Casa Loma. From Casa Loma south-eastward, Hill shows the fault present but masked by the valley filling to a point at the foot of the hill one and one-half miles southeast of Vallevista. Southeastward from here its course through the mountains between Bautiste Creek and the San Jacinto River, to its southern end at the northwestern corner of the Ramona Indian Reservation in the north end of the Terwilliger Valley, is the same as that traced by Strong and Rolfe, except that the latter carry it through Hog Lake, while Hill places it considerably west of this lake. As Hog Lake is one of the most characteristic forms of fault topography in the entire region under discussion, it seems reasonable to locate the fault trace through this depression.

Hill maps another fault, beginning at "B. M. 2062" at the mouth of the San Jacinto River canyon and extending southeasterly up the South Fork of the San Jacinto River, thence along the southwestern face of Thomas Mountain, to Hamilton Creek, and thence following the course of the San Jacinto fault as traced by Strong and Rolfe. Hill also maps a third fault, called the Coyote Creek fault in this report, directly paralleling the southeastern portion of the San Jacinto fault but two and one-half miles farther southwest. The Coyote Creek fault starts in the headwaters of Bautiste Creek, passes through the center of Terwilliger Valley, through Coyote Canyon, thence along the northeastern edges of Collins and Borego valleys and Borego Mountain into the valley southeast of this mountain.

Hill extends the Reche Canyon fault, which the writer believes is part of the main San Jacinto line, through the hills at the northern end of the San Jacinto Valley; thence it is marked as questionable, owing to the valley filling, along the southwestern edge of the San Jacinto Valley where it terminates the various granite masses which more or less imperfectly define this side of the valley. A continuation of this fault, shown as the Red Mountain fault on the map, is shown as passing along the northeastern flank of Reservoir Butte, three miles southeast of Hemet, thence through the hills, of which Red Mountain is a dominating peak, more or less roughly paralleling Bautiste Creek, to the northwestern end of the Terwilliger Valley, approximately two miles southwest of the northwestern end of the Coyote Creek fault.

Minor faults are also shown on the southwest side of the mountains immediately northeast of the Box Springs Mountains. These faults are questionably continued southeasterly to the middle of the Lakeview Mountains, roughly paralleling the fault described as passing along the southwestern edge of the San Jacinto Valley.

Short faults are also shown paralleling the northeastern edge of the San Jacinto Valley, distant three miles from the valley, beginning at the vicinity of Potrero San Jacinto Nuevo, extending northwesterly for four miles and southeasterly for twelve miles. A fault is also indicated as passing between the southeastern end of Hemet Valley and the northwestern end of the valley southwest of the middle portion of the Santa Rosa Mountains.

It is the writer's belief that the fault which Hill maps as bounding the San Jacinto Valley on the northeast, and which Hill considers part of the main San Jacinto fault, passes about one and three-quarters miles east of San Jacinto along the base of the hills, through the hills west of the lower reaches of the San Jacinto River, and thence into the canyon of the south fork of the same river, thence along the upper part of the northeastern flank of Thomas Mountain, thence along the southwestern side of the southeastern extension of Hemet Valley, through the uppermost reaches of Horse Canyon, and so on down into the desert region north of Clark Lake. The writer has called this fault the Hot Springs fault, for purposes of description in this paper, the name coming from Relief Hot Springs, a point on the fault four miles north of San Jacinto. Strong and Rolfe found a point of excessive disturbance in one of the upper forks of Horse Canyon about one and one-half miles southeast of Lookout Mountain, which would fall in line with the location of the fault as described above. In general, this fault parallels the main San Jacinto fault, as described in this paper, throughout practically its entire length from the San Bernardino Valley to the desert region west of Salton Sea, and, in connection with the Coyote Creek fault, gives three almost uniformly parallel lines for a distance of many miles. Such a system accounts for the topography and geology of the San Jacinto Valley and connects with the three faults described by Hill as passing through the hills southeast of Colton.

REMARKS ON THE SONORA EARTHQUAKE—ITS BEHAVIOR AT TEPIC, SONORA, ETC.

By BERNARD MACDONALD

I have listened with great interest to Mr. Staunton's recital¹ of his personal experience with the Sonora earthquake in the underground workings of the Tombstone mines. My observation of the "doings" of this earthquake, while it was in actual operation, was at Tepic (?) or Tepachi (?), a little farming village situated six miles south of Cumpas, on the wagon road between this latter town and Moctezuma, in the state of Sonora, Mexico. Tepic is distant approximately 120 miles south of Tombstone, Arizona.

The earthquake occurred in the year 1887, on the 3rd of May (the "fiesta de La Cruz" of the Mexican miners), at 3:20 in the afternoon. At this time I was superintendent of the Santa Ana Mining Company, then engaged in equipping the "Santa Ana" with pumping and hoisting machinery. The Santa Ana is an old mine with a bonanza record (according to Ward's history of Mexico), and is situated about fifteen miles west of Cumpas.

On the day of the earthquake I left the mine in the morning and came to Cumpas to hurry out some mining machinery that had arrived there the day before by teams from Fairbanks, Arizona, which at that time was the nearest railroad station. On reaching Cumpas, I found that our teamsters, who were mostly Arizona Mexicans, had caught the spirit of the miners' festival and were too much "enthused" to be induced to start for the mine that day. The festivities of the day were staged to take place at Tepic that afternoon and night, so I went there to see the celebration.

An outdoor public ball had opened in the afternoon under an arbor erected on the plaza, and the people were dancing or promenading around to the music. The day was one of those bright, warm, sunshiny days peculiar to Mexico, and the sky was unmarred by a cloud. I was sitting on a bare tree fallen by the side of the plaza, contemplating the gay colors of the dancing mass in the checkered sunbeams falling through the green arbor overhead and making a harmonious blending with the surrounding tropical scene. I have often thought

¹ *Bulletin of the Seismological Society of America*, 8, 25.

since, in reflecting on this scene, how impossible it would have been to imagine then that in a few seconds that gay gathering would be scattered throughout the town in little groups of cowering suppliants asking for celestial intervention and protection. But such was the case, nevertheless. At 3:20 the thrum, thrum of the music, the swish, swish of dancing feet, and the gay chatter of the promenading crowd were interrupted by *bump, bump, bump*, three distinct, tremendously loud subterranean knocks, coming about one second apart. These bumps seemed to "knock the props" from underneath the plaza, leaving the ground a swaying, vibrating, creaking shell, accompanied by an indescribable conglomeration of crushing, grinding, and rumbling noises. The ground oscillated, sunk, rose, and trembled, sending up into the air immense puffs of acrid, blinding dust as if from hundreds of cyclopean bellows. The crowd was instantly panic-stricken and ran hither and thither, falling and sprawling as they went. The whole cataclysmic occurrence, which seemed an *earthcrush* rather than an earthquake, appeared to be located immediately underneath the plaza, and, to escape being swallowed up, I ran, like the others, toward the uphill side of the town. As I started to run I saw the three earthwaves rolling across the plaza toward me. *These waves seemed to be two feet high, about twenty feet apart, and moved as rapidly as the incoming waves along the seashore.*

At the risk of throwing suspicion on the credibility of the statement in the last sentence, I have underscored the remarks because the phenomenon of the solid rocky surface wrinkling up into waves, traveling rapidly (westward) across the plaza and smoothing out again, is so physically improbable that I want it to stand out as it then appeared to me.

In running away from the plaza I fell across one of these waves, but lost no time in resuming the flight. When I had reached the distance of seventy or eighty yards up a street running out from the plaza, the crashing and rumbling sounds had subsided to a subdued shiver. I turned around to see the expected cave-in at the plaza, and was surprised to find that nothing of the kind had happened. However, in the mountains to the southwest, which were under vision for a distance of twenty miles, the travel of the earthquake going west was plainly visible. On the nearer mountains great columns or pillars of dust were standing out here and there, and other columns of dust were rising over the farther hills. This made an awe-inspiring scene, accompanied, as it was, by reverberating reports like immense blasts

or explosions, and for the reason that I had mistaken the dust columns for smoke columns of incipient volcanoes. These reports ceased and the shiver of the ground underfoot died away gradually, and then came an after-stillness that for the first few moments intensified the apprehension that "the worst is yet to come."

Thus ended the first and main "quake" of the series. I looked at my watch and it was 3:25, and, as I estimated that the duration of the shock was about five minutes, I set its commencement at 3:20. How those few minutes had changed the scene! The plaza and streets were deserted; the people were scattered in small groups over the hillside or huddled together in the interior patios. The women of the groups were leading in prayer. All believed the *fin del mundo* was coming on, for, as I understood afterwards, no other earthquake had occurred within the memory of the inhabitants or in their tradition. Therefore the people believed that the "crush of matter and the wreck of worlds" had been inaugurated.

This earthquake was followed by another in just five minutes, and, with appalling regularity, in intervals of five or six minutes other earthquakes followed for about two hours. The shocks continued throughout the night with a duration of from ten to thirty seconds, but with decreasing frequency. I retain the impression, however, that for the remainder of the night a fairly strong shock occurred every half hour. The frequency changed to one every two or three hours during the next day and then decreased to two or three a month for the following six months, when they practically ceased altogether, and so far as I have heard no earthquake has since occurred in that region.

The effect of the first shock was disastrous for the little town, for although the houses were low and squatty and of one-story adobe construction, the walls and roof of every house were shattered—the walls of many had fallen out and the roofs fallen in. The plaza and streets were ripped up by fissures, some as wide as six inches or more, and the irrigation ditches around the town were all broken. In about half an hour after the first earthquake the sky turned to a brownish color and the sun appeared as red as blood. The sunset that evening was gorgeous. Although there was not a cloud in the sky, every color of the rainbow was represented, with changes into wonderful combinations of blendings. This was doubtless due to the dust with which the air was laden almost to suffocation through the evening.

I found in riding over to the mine the next day that the road was crossed at various places by fissured zones in which the ground was

cracked for considerable distances. Pre-existing water holes had changed to flowing springs, other water holes had dried up, and a new spring had started and was flowing copiously in the middle of the road at a point where no water had previously existed for three miles on either side. At the mine the only underground work going on was a cross-cut tunnel, which was in about 400 feet. There was no caving anywhere in this work, but the miners said the tunnel "swayed back and forth" and the rumbling and grinding noise was frightful all the while they were running out to daylight. On the surface the workmen handling the machinery ran away from the yard when "the ground commenced to sway and sink" and the material to "rock and reel over the yard."

A few days after the earthquake I had occasion to visit Moctezuma, the capital of the district, a town of some 3,000 inhabitants, situated about twenty miles south of Tepic. Here I found the houses wrecked in the same manner already described, and all the inhabitants living out of doors in shelters erected in the streets and patios. The prefect of the district had prohibited anyone from living in the houses, and this regulation lasted for six months after the first shock. The information had reached Moctezuma that the effects of the earthquake were strongly manifested among the small hamlets and villages for 100 miles south of the town. The reports from the section of the country lying east of the Cumpas or Oposura river indicated that the earth shocks were more severe in that region. A report was current that there were forty persons killed in a church in Oputo, a town thirty-five miles northeast of Tepic. At the first shocks the women and children in this town ran into the church, then the walls shattered and the roof fell in. In this neighborhood it was reported by American prospectors that a fissure two and a half feet wide was created by the shock and remained open until filled by the rains in August following.

Two weeks later I drove up to Tombstone, our outfitting point for the mine, over the road leading through Nacosari, Fronteras and by the sites of the towns now Agua Prieta and Douglas, since built. For long distances, at places, this road was fissured by wide, deep cracks, and so badly that I was obliged to make long detours, driving slowly, to get over the cracks. There were several new springs and water holes along the road, and at places the road was turned to quagmires. At Tombstone the streets were cracked and fissured, as were the walls of many of the houses. Reports stated that similar evidences of the

earthquake were visible as far north as Globe and Clifton. The open fissures and the larger ground cracks left by the earthquake coursed through the country in a north and south direction, but these were joined by a network of smaller cracks. I returned to the mine by the road that went through the old San Pedro custom house and along the easterly headwater branch of the Sonora River and the town of Bacuachi. This road lies about thirty-five miles west of the Nacosari road, but it was just as badly fissured as was the Nacosari-Fronteras road.

I think it is conservative to say that the area fissured and cracked by the shocks of this earthquake covered a length of 350 miles by a width of 100 miles, or 35,000 square miles, an area approximately as large as the state of Indiana, and possibly twice this area was sensibly shocked, if not scarred, by the first earthquake.

It may be interesting to note here that in the months which followed the first earthquake I had frequent opportunities of observing the behavior of my dog during the smaller earthquakes that continued at irregular intervals during this period. The dog sensed the coming of an earthquake for some seconds before I could detect it by either sound or shake. Whether outside or inside the house, he would run and throw himself on my feet and give a low, complaining whine, then the shiver of the earthquake would become perceptible. The night following the first earthquake I slept at Tepic in an open patio, at one end of which a flock of chickens roosted. While the earthquakes, which came frequently during the night, were in progress the chickens would cluck complainingly, but after the shock was over the rooster would crow vigorously and defiantly and the roosters in the neighborhood would join in the chorus.

The five minutes or so during which the first earthquake lasted was the most selfish period of my life. Like the others, I was absolutely possessed of a feeling of "let him who can save himself."

This had been my first earthquake experience, and I have often wished since to have the experience repeated so that I might deliberately and calmly study the progress of the phenomenon. Only for a brief period of the whole experience I appreciated, if I did not enjoy, the majestic grandeur of that cataclysm; that was when I watched the dust columns rising in an advancing procession over the distant hills and heard the reverberating salvos of the earth shocks coming back from these hills, like the reports of 42 centimeters, as the earthquake was passing over the mountains to the southwest.

South Pasadena, Cal.

THE STARTING POINTS OF EARTHQUAKE VIBRATIONS

By HARRY FIELDING REID

In the June and December, 1917, BULLETINS Dr. Klotz made the interesting suggestion that when an earthquake is caused by movement on a long fault, the records at different observatories may locate different points on the fault and thus indicate its length and position. A particular instance cited was the earthquake of May 1, 1915, on the margin of the Kurile Deep. The origin had been located by records from a number of stations, and later a copy of the Perth seismogram indicated, by the length of the first phase, that the origin was 500 kilometers nearer Perth than the position earlier assigned to it. This was supported by the Zi-Ka-Wei and Honolulu records. The conclusion was drawn that different stations record disturbances starting from different parts of the fault and thus make it possible to locate not only one point, but many points of the fault. This is such an interesting matter that it calls for careful analysis.

In figure 1, let O_1O_2 represent a fault; great circles at right angles to the fault would meet at two points 90° distant from every part of the fault; and the first record at stations situated near these points would come from that part of the fault where a shock, strong enough to make a record at C , first took place. If the fracture occurred simultaneously all along the fault, the beginning of a record at a station would be due to the point on the fault nearest to it. The nearest point to a station within the lune CC' would depend on the position of the station; one end would be the nearest point of the fault to stations outside the lune.

But the simultaneous fracture along the fault is impossible. It would require the gradually accumulating stresses to reach the locally varying strength of the rock at all parts of the fault simultaneously. What must necessarily occur is this: The elastic stresses become sufficient to cause a fracture at some point; the stresses at this point are then transferred in part to neighboring points, which in turn break down; and so the fracture is propagated. Where the movement on the fault is horizontal, the stresses would apparently be transferred by compressions and rarefactions; where the movements are vertical, by distortions. Under any circumstances the stresses cannot be trans-

ferred at a greater speed than that of the longitudinal elastic waves, which is therefore the greatest possible speed for the extension of the fracture; the actual speed is undoubtedly variable and probably considerably less than the maximum.¹

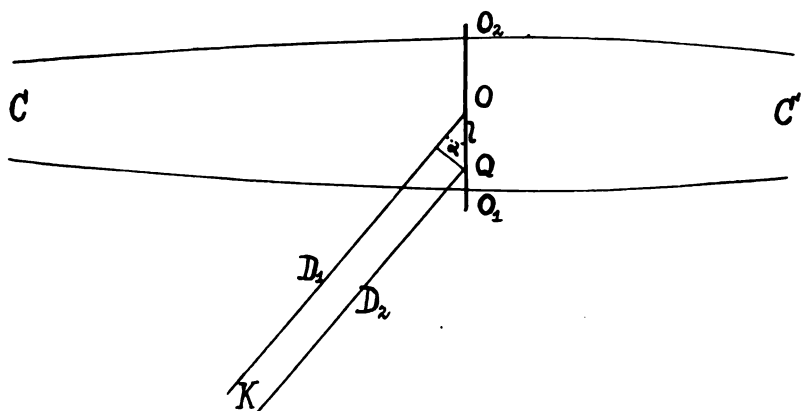


Fig. 1.

Assuming then that the fracture is extended at the maximum rate, which we may take at 7.2 kms. per second, let us see what point of the fault sends its disturbance first to a station K . Let D_1 be the distance along the great circle from the point O , where the strong disturbance commences, to the station; D_2 the distance from some other point Q of the fault. The average velocity along D_1 is slightly greater than along D_2 , and distinctly greater than the speed of fracture along l ; and since the path $l + D_2$ is longer than the path D_1 , the disturbance will reach K along the path D_1 before it will along the path $l + D_2$. The beginning of the station's record will be due to the point on the fault where the disturbance begins; which generally would not be the point of the fault nearest to the station.

The P phase, as we have seen, is comparatively easily dealt with, because the speed of the extension of the fracture is smaller than the speed of propagation of the disturbance. But the S phase is somewhat more complicated. Let the disturbance at O be strong, and let the fracture be propagated towards O_1 . Let T_1 and T_2 be the times required by the S waves to travel, respectively, from O and Q to K ;

¹ See "Mass Movements in Tectonic Earthquakes and the Depth of the Focus"; *Beitrage zur Geophysik*, 10, 345, 1910; or, "The Elastic Rebound Theory of Earthquakes," *University of California Publications: Geology*, 6, 432.

we shall suppose the station sufficiently distant to permit us to consider D_1 and D_2 as parallel near the fault. Let v be the speed of extension of the fracture, whose maximum value is 7.2 kms. per second. The time for the S waves to pass directly to K will be T_1 ; the time for the fracture to extend to Q and the S waves, starting there, to reach K will be $l/v + T_2$. For the latter to reach K first, we must have

$$\frac{l}{v} + T_2 < T_1 \quad (1)$$

We may replace T_2 by $T_1 - \Delta T$, where $\Delta T = T_1 - T_2$; and the inequality becomes

$$\frac{l}{v} < \Delta T \quad (2)$$

ΔT is the time necessary for the S waves to cover the distance $D_1 - D_2$, or $l \cos \alpha$, where α is the angle between D_1 and the fault. If v_1 is the average surface velocity between the distances D_2 and D_1 , then $\Delta T = l \cos \alpha / v_1$. We can find v_1 from the transmission curve; it is not constant, but is greater as D_1 is greater and as $D_1 - D_2$ is less, as it is measured backward from time corresponding to D_1 . Our inequality may now be written

$$\frac{l}{v} < \frac{l \cos \alpha}{v_1} \text{ or, } \cos \alpha > \frac{v}{v_1} \quad (3)$$

We have seen that v_1 gets smaller as $l \cos \alpha$ becomes larger; but if the length of the fault measured from O is 4° , or 445 kms., and the station is about 36° from the fault, then v_1 will equal 7.2 kms. per second, and $\cos \alpha$ becomes unity. For all stations at a greater distance than 36° and faults not more than 445 kms. long, v_1 becomes greater than v , α becomes imaginary, and the first recorded S waves must start from O . If, as seems perfectly certain, the speed of fracture is less than 7.2 kms. per second, then the first recorded S waves will come from O for distances even less than 36° . If the speed of fracture is as small as 4 kms. per second, the lowest speed of the S waves, then O will be the starting point of the S waves for stations at all distances. This last condition is, not improbably, fairly general. The only facts I know having any bearing on the speed of propagation of the fracture are connected with the California earthquake of 1906. The fracture apparently began a little northwest of the Golden Gate; the violent shock did not take place until a half-minute later, and had its origin about 30 kms. further to the northwest.² These points are not accurately determined, nor do we understand the dynamics of fracturing

² "The California Earthquake of April 18, 1906," 2, 5-11. The Carnegie Institution, Washington, 1910.

well enough to interpret the facts with confidence; but they suggest strongly that the fracture in this case was not propagated very rapidly.

A graphic representation of the two terms of inequality (2) shows that if the speed of fracture is sufficient to make the *S* waves start from a point on the fault nearer the station than *O*, they will start from the end of the fault and not from an intermediate point, if the station is outside the lune *CC'*; or from the nearest point to the station, if it is within the lune.

The treatment of the surface waves is like that of the *S* waves; but we do not know where they start. They must be set up by the arrival of the longitudinal or distortional waves somewhere at the earth's surface, but not necessarily at the epicenter.³

If a strong shock is sent out from a point very near where the fracture begins, all stations, very probably, receive their first *P* and *S* waves from this point, and not from the ends of the fault. But another procedure is possible. Suppose the fracture starts from a point where the stresses are small and the rock weak, and extends in opposite directions to places where both the stresses and rock are strong. Heavy shocks might occur at not very different times at two points many kilometers apart; and these might be the first shocks strong enough to be recorded by our instruments. The *P* and *S* waves recorded at a station would refer to the nearer of the two points mentioned. Something of this kind may have happened at the time of the Kurile earthquake; and it seems *a priori* probable that the fault ran parallel to the Kurile Deep; but the seismographic evidence does not seem sufficient to establish the fact. The record from Manila, which is nearly in the line of the probable fault, indicates an origin about 165 kms. nearer than Dr. Klotz's northern focus.⁴

Dr. Klotz's suggestion opens up many interesting questions, and, as he says, their solution depends upon the accumulation of *accurate* records. This cannot be too strongly emphasized. I believe more real information could be extracted from the records of a half-dozen stations where the time error is negligible than from many times that number where the clock error is not known.

Johns Hopkins University.
Baltimore, May 15, 1918.

³ This was discussed in the Report on the California Earthquake of 1906, 2, 126.

⁴ It is also to be noted, that if the fault parallels the Kurile Deep, Honolulu is nearer the northern than the southern focus and should not be used to determine the latter.

ANALYSIS OF EARTHQUAKE WAVES

By OTTO KLORZ

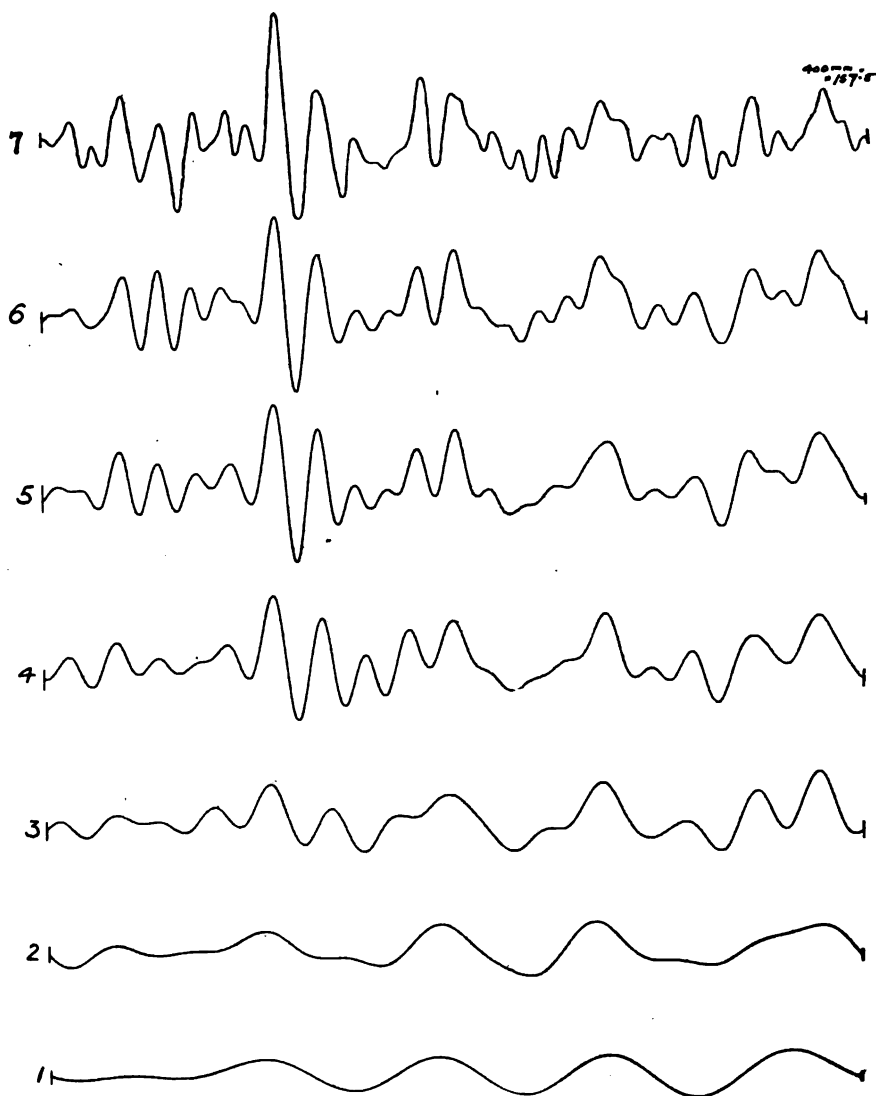
When Professor Dayton C. Miller, of the Case School of Applied Science, Cleveland, gave his splendid popular address with the marvelous illustrations of his Phonodeik on the Science of Musical Sounds, before our Royal Society at Ottawa last May, I was struck by some of the compound waves shown as resembling some of our *L* waves, and the idea of analyzing earthquake waves by means of his improved Henrici Harmonic Analyzer immediately suggested itself to me.

On the following day he gave a short talk before our section,—Mathematics and Physics,—and closed by offering to analyze any periodic curve for any member. I was not slow to accept the offer, and arranged to have the necessary material furnished. The earthquake of September 7, 1915, off the Pacific coast of Central America was selected. The analyzer and the 32-element harmonic synthesizer to which reference will subsequently be made were described by Professor Miller in the *Journal of the Franklin Institute*; the former in September, 1916, and the latter in January, 1916.

Whatever part of the seismogram is selected for analysis, that part which is chosen for a period, which it may be stated is not very easy, must be enlarged to exactly 400 mm. in order to fit the machine—the analyzer. From the seismogram of the above earthquake were chosen six sections, three from each component, N-S and E-W, viz: the beginning of *P*, which was sharp; the beginning of *S*, which was not so abrupt as *P*; and a section of *L* on which the *L* waves were obvious. The mathematical process of analysis by Fourier series is too time-consuming, as the writer found out years ago, to apply the many analyses one wants, so that one interprets or reads the periods or supposed periods directly from the seismogram, knowing at the same time that it is a questionable procedure.

The above parts chosen were enlarged photographically to the required 400 mm. and forwarded to Professor Miller to await my arrival from the eclipse expedition to Denver.

On June 13th I spent the day with Professor Miller to see and learn the *modus operandi* of the analyzer and synthesizer. It should



Earthquake September 6-7, 1915. S wave, E-W component. Ottawa. Analysis by Dayton C. Miller.

1. Synthesis of components 1 to 5.
2. Synthesis of components 1 to 10.
3. Synthesis of components 1 to 15.
4. Synthesis of components 1 to 20.
5. Synthesis of components 1 to 25.
6. Synthesis of harmonic components 1 to 30 inclusive.
7. Enlargement of original record from seismogram.

[The scale of the photograph furnished by the author was 400 mm. = 157.5 sec. This reproduction has been reduced in the ratio of 109 to 150.—Ed.]

have been stated before that the seismograms are from our two Bosch seismographs, with photographic registration; mass or bob of each horizontal pendulum 200 grammes, magnification 120.

For illustration to me of the mechanical work, the gram of the *S* waves of the E-W component, magnetically damped, was chosen. The enlarged gram covering 400 mm. represented $157^{\circ}.5$.

The harmonic analyzer is adapted for thirty components, that is, the analysis of a periodic wave will show which of the simple thirty sine waves are concerned and to what degree, as shown by the amplitudes, in producing the periodic wave. The 400 mm. of the periodic wave represents some definite time interval, and it is assumed that in the next similar time interval a similar periodic wave will be produced. The thirty components represent simple sine waves whose periods are respectively the quotient of the period of the composite wave divided by the respective component; the 30th component will have a period half as long as the 15th; or a third of that of the 10th, and so on.

The analyzer takes five components at a time, so that for the thirty, six tracings or followings with the stylus of the gram of 400 mm. are necessary.

On the day of my visit Professor Miller used the components from 11 to 25, fifteen in number, and read off the sine and cosine terms on the graduated wheels, from which the amplitudes were mechanically obtained and also the phase angle; the ratio sine, cosine gave the angle, and their respective signs the quadrant. Then transferring the constants thus obtained to the synthesizer, and turning a handle—presto!—the periodic curve dependent upon those constants was produced, or drawn in ink on the blank sheet. It showed a fair resemblance to the original, and the writer saw and appreciated the great assistance the analyzer could render the seismologist, for the periods of earthquake waves are not yet satisfactorily known on any seismogram.

Professor Miller, not being satisfied with the partial analysis, examined the gram later and applied the remaining elements, 1 to 10 and 25 to 30, to the other fifteen and sent the results to Ottawa. It may be remarked that the writer considered that he had taken rather too much (in time) of the original gram to represent the *S* waves, however it served for experimental purposes.

The results of the analysis are given in the subjoined table:

Components—														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Periods of Simple Sine Waves—														
157 ^s .5	78.7	51.8	39.4	31.5	26.2	22.5	19.7	17.5	15.8	14.3	13.1	12.1	11.2	10 ^s .5
Amplitudes in mm.—														
1.0	1.4	2.8	5.4	6.6	1.7	2.6	0.5	0.5	2.4	1.5	5.8	1.1	2.3	3.6
Phase Angle—														
102°	154°	166°	154°	286°	132°	225°	208°	214°	187°	248°	334°	293°	69°	18°
Components—														
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Periods of Simple Sine Waves—														
9 ^s .8	9.2	8.8	8.3	7.9	7.5	7.2	6.8	6.6	6.3	6.1	5.8	5.6	5.4	5 ^s .2
Amplitudes in mm.—														
3.0	5.2	4.3	4.1	5.9	4.4	3.8	2.8	2.4	3.6	2.7	0.6	4.0	1.6	1.4
Phase Angle—														
290°	198°	26°	281°	150°	110°	10°	245°	37°	282°	219°	162°	82°	342°	20°

From the amplitudes the governing simple sine waves become evident. From the above we find five marked periods standing out from their respective adjoining ones, 39^s.4, 31^s.5, 13^s.1, 7^s.9 and 5^s.6. The amplitude of such long periods as of the first two is not obvious. The next largest amplitude is for the period of 7^s.9, say 8 seconds, and this is a period that is not unusual to note when the period of *S* can be read at all satisfactorily. However, the most interesting fact brought out by the analysis, and one of the main reasons for communicating this brief note, is the amplitude for component 28, period 5^s.6, which stands out boldly between its neighbors. It is the period of the pendulum at that time. In our first partial analysis comprising the components from 11 to 25, the periods between 14^s.3 and 6^s.3 only were covered, and hence the presence of the motion of the pendulum was not detected. When, however, the remaining components were added the hidden effect of the pendulum, which as it is magnetically damped was considered practically aperiodic, was exposed, and the lurking enemy brought to view. It will be observed that the analyzer sharply differentiated between the periods of 5^s.8, 5^s.6 and 5^s.4. It would hence appear,—awaiting confirmation in further analyses,—that the analyzer is able to determine the period of the pendulum to the tenth of a second, a precision equaling that of direct observation. If true, as it appears, it is a great achievement.

Now a few words about the accompanying diagram. The unnumbered reproduction at the top is a facsimile of part of the seismogram

for the *S* waves on the E-W component, magnetically damped. The beginning of the *S* waves was taken on the original as shown by the left-hand end at the short vertical line. The right-hand end was more or less arbitrary, only observing that the periodic curve might be assumed there to begin repeating itself. The numbered diagrams represent the syntheses respectively of the elements 1 to 5, 1 to 10, 1 to 15, 1 to 20, 1 to 25, and 1 to 30. When we examine No. 1, involving only five elements, and look at the harmonic analysis table, we find that the wave 31.5 is the controlling factor, yet materially affected by the adjoining one of 39.4 , as is evident when we find the phase angle of the one 286° and of the other 154° , so that in the beginning their amplitudes are of opposite sign and neutralize each other, and further on are more concurrent. This may be readily illustrated by drawing two sine curves of the respective periods and amplitudes, and superposing the one on the other, making the points represented by the phase angles 286° and 154° respectively lie in the same vertical. On the diagram the two fairly uniform waves have a period of 33.2 . Thus proceeding through the remaining five diagrams, each having added five elements, we come to No. 6, which includes the thirty terms of the analyzer and gives us a pretty good gram of the original seismogram. Further analyses will undoubtedly give still greater accordance. It is believed that this is the first time earthquake waves have been subjected to this method of analysis.

The amplitudes as stated are in millimeters, based on the diagram (enlarged seismogram) over which the stylus passed. Now this diagram was magnified from the original seismogram about ten times, while the theoretical magnification of the seismograph is 120, so that roughly we have 1200 as the magnification, and an amplitude of 6 mm. would in reality represent a movement of the earth particle of $6/1200$ mm. or 5μ , a pretty small quantity, although representing about the largest amplitude measured.

My object in communicating this brief and imperfect note is to show the possibilities that the analyzer and synthesizer, more particularly the former, offer to the seismologist in unraveling some of the great number of facts buried in the seismogram, and of which we are still woefully ignorant. It is hoped that in the near future the writer will submit a more complete analysis, comprising the *P*, *S* and *L* waves for both components and of the same earthquake.

Dominion Astronomical Observatory,
Ottawa, July 2, 1918.

AN EXPERIMENT IN TELESEISMIC REGISTRATION

BY T. A. JAGGAR AND ARNOLD ROMBERG

The requirements for registering teleseisms usefully are a slow-period pendulum, as little friction as possible, known constants of apparatus, a high damping ratio approaching aperiodicity, magnification so related to damping as to reproduce the relative amplitudes of various earth movements as nearly as possible proportionately, and a chronograph sheet moving fast enough to make an open record easily divisible to seconds of time.

The Omori 100-kilogram horizontal pendulum, made in Tokyo, was used, but the smoked paper and stylus were replaced by an optical system as follows: a one-ampere lamp with straight filament was set up 150 centimeters from the end of and in line with pendulum arm and somewhat higher. The tip of the arm was equipped with a magnetized steel needle protruding horizontally, and a second magnet of the same size was waxed to the center of the back of an ordinary light circular mirror 12 millimeters in diameter. This second needle stood at right angles to the mirror with its north pole close to the south pole of the arm magnet. The mirror was cemented to vertical taut silk fiber 8 centimeters long, held on a post standing on a concrete table. Horizontal displacement of the earth hence moved pendulum support and mirror support, while the frictionless magnets rotated the mirror around a vertical axis in response to inertia of the heavy mass. In case of a sharp local shock the mirror would be uninjured, as the magnets would part. The light beam was focused through and past the mirror with an anastigmat lens of approximately 30 centimeters infinity focus on a kodak film wrapped around the chronograph drum. The drum was speeded to about 32 millimeters per minute. The time-marking system was an improvised rocker actuated by an electro-magnet wired to the usual minute-contact time-piece, the rocker breaking the light circuit by lifting a copper terminal out of a mercury cup. Once a minute the light was thus extinguished, making a break in the photographically written line on the film, and once an hour a longer break was registered.

The pendulum was damped to a ratio four to one by attaching beneath the arm a perforated metal box immersed in a mixture of medium automobile oil and heavy vacuum (steam-engine) oil. The

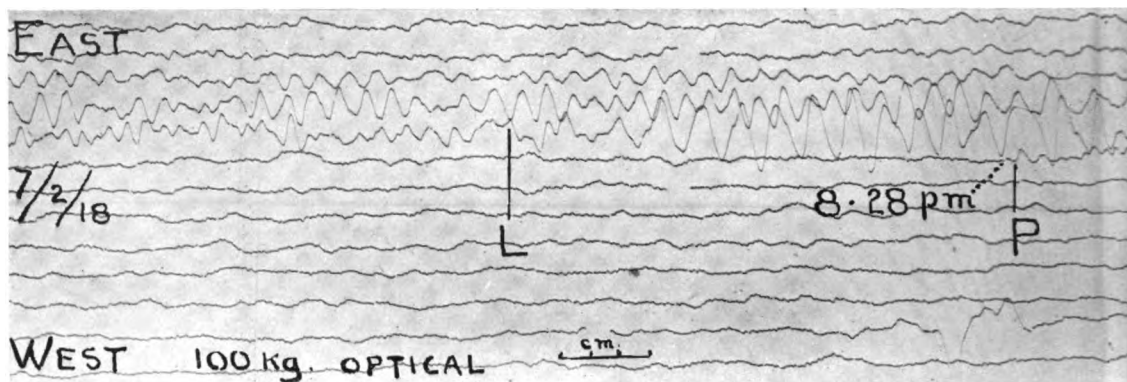


Fig. 1. Optical record on

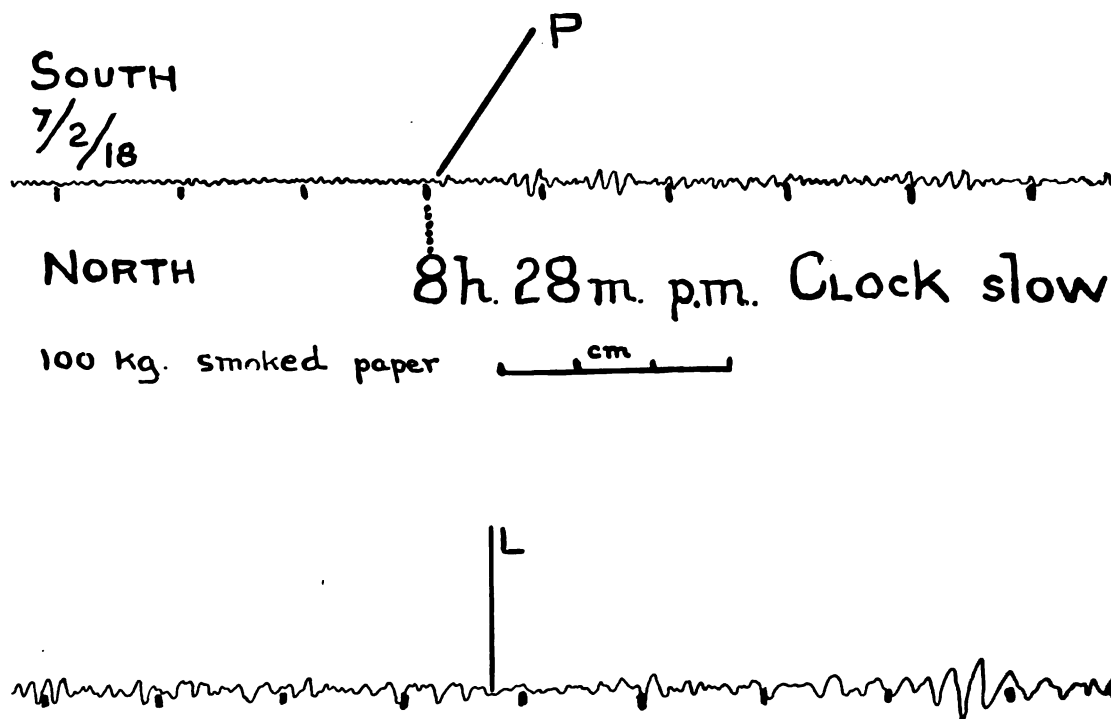
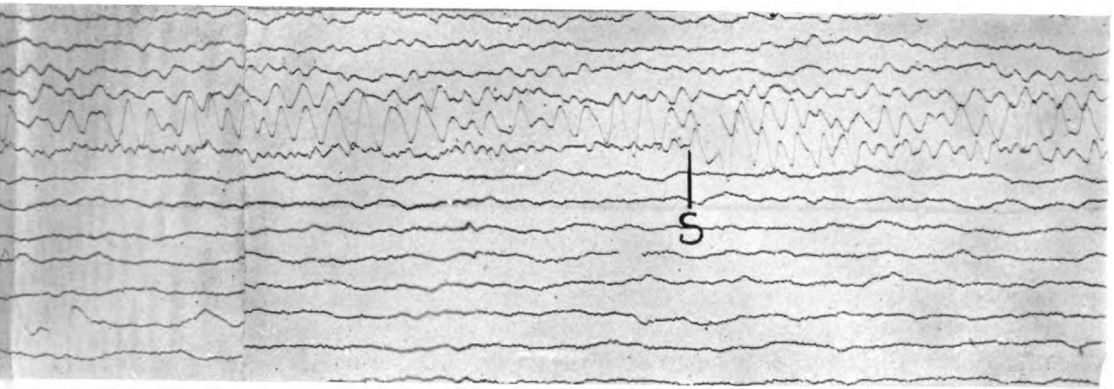
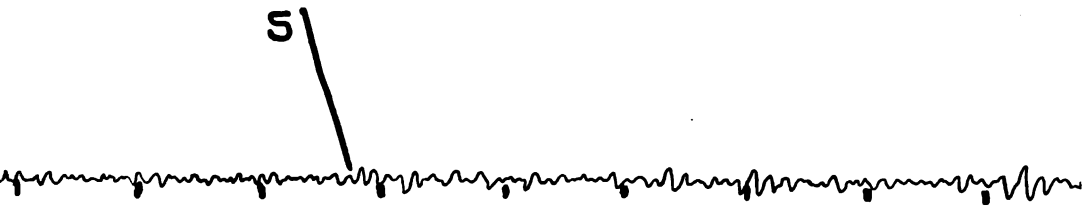


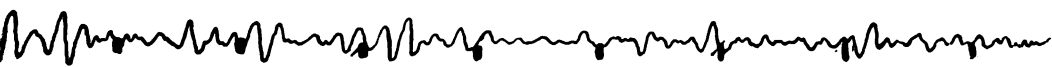
Fig. 2. Tracing of



m. magnetic transmission.



10h.34m.14s.G.M.T.



oked-paper record.

mirror was damped, to prevent any possible quick vibrations of its own, by attaching to it and beneath it, in a test-tube of medium automobile oil, a light vane of mica.

The linear magnification (V) of rapid movements of the earth was approximately 200; the period of the undamped system was approximately 14 seconds, and when damped 14.7, as shown on the two decay curves in the lower part of seismogram (Plate 15, Fig. 1), made artificially by the attendant walking around the pier. The solid friction was very small and resides in the pendulum supports. At all times the graphs indicated great sensitiveness to microseisms and to the local micro-tremor believed attributable to the Hawaiian volcanoes on which the observatory is seated. They confirmed the evidence of earlier non-optical records which indicated that this volcanic trembling is harmonic and incessant, of period approximately one-half second. This minute sinuosity of the line is lost in reproduction, but very plain on the original film.

The particular seismogram of July 2, 1918, here reproduced, shows a teleseism initiated at 8^h32^m20^s Hawaiian Standard Time (G. M. T. 7^h02^m20^s July 3d), the first (P) and the second (S) preliminary phases being exhibited with extraordinary clearness. The duration of the P tremors was 8^m36^s. The same earthquake was registered on smoked paper simultaneously by two Bosch-Omori 100-kilogram instruments in the same room, but with no such definition of phase. (Fig. 2, N-S component drum speed 16 millimeters per minute; magnification 100; air damping 3 to 1.) It should be noted that the times of P , S and L indicated on this figure are transferred from the optical seismogram for comparison.

It will be seen that the optical record is similar to the Galitzin graphs as published by Walker.¹ The Galitzin instrument, however, records galvanometrically, so depends on velocity, whereas the present instrument registers direct displacement. The Galitzin method, even though aperiodicity is used, tends to exaggeration in the long (L) waves, whereas it will be seen in the present seismogram the long waves, though showing some resonance with the period of the pendulum, are of very moderate proportions, and with heavier damping would probably show amplitudes still smaller. The initial movements of P and S , on which seismographic measurement of distance and direction is dependent, are sharp and unmistakable and quite similar in character to those obtained by the galvanometer method.

Hawaiian Volcano Observatory.

¹ "Modern Seismology," by G. W. Walker, Plates 11 and 12. Longmans, Green & Co., 1913.

SEISMOLOGICAL NOTES

The Board of Directors of the Seismological Society of America take pleasure in announcing that a grant of \$250 has been received from the American Association for the Advancement of Science, to be used in the immediate investigation of earthquakes occurring in the Pacific Coast region of North America.

Southern California, March 6, 1918.—An earthquake was felt in Los Angeles and vicinity on March 6, 1918, at 10:20 a.m. This shock was also felt in Venice, Santa Monica, Culver City and Hollywood, according to press reports. As usual, this shock was reported as the result of some mysterious explosion. From meager reports received it appears that the epicenter must have been in the ocean, west of Santa Monica and Venice. At these places the intensity seems to have reached V, possibly VI. The shock was reported as far north as Van Nuys, in the San Fernando Valley, where the intensity was about IV.

In the southern portion of Los Angeles the intensity reached IV, possibly V, but was much less in the northeastern portion of the city. The shock was abrupt, of about one to two seconds duration, and some observers noticed distinct earthquake sounds.—Homer Hamlin.

Kern County, California, March 23, 1918.—An earthquake was felt at Brown and Little Lake, in Kern County, on March 23, 1918, at 7:15 a.m. It consisted of one short shock, and caused decided jarring of buildings, etc., and slight displacement of furniture. The intensity must have been V to VI. This slip evidently occurred along the eastern Sierra Nevada fault zone. It was noticed by at least five persons. Information furnished by Mr. William High, Brown, Cal.—Homer Hamlin.

Virginia, April 9, 1918.—The newspapers report an earthquake in the state of Virginia and in the District of Columbia between 8 and 9 o'clock p.m., April 9, 1918. The editors hope to be able to publish a full account of the shock in the next number of this BULLETIN.

Washington, D. C., April 10 and 20, 1918.—An earthquake was felt at Washington on April 10, 1918, shortly after 1 o'clock (G. M. T.). The seismographs of Georgetown University indicated the maximum at 1:9:34 and an amplitude of 1.6 mm. The intensity was III-IV in the Rossi-Forel scale. The shock was reported as felt at Lynchburg and at Richmond, Virginia. Letters were received from Woodstock, Maryland, stating that slight tremors were experienced in that region. Windows were broken in the immediate neighborhood of this observatory. On April 20th a shock was felt by people here and also by myself, and although the seismographs indicated a trace at 11:26, it is not believed that this shock was of seismic origin.—Francis A. Tondorf, S. J., Director Georgetown Seismic Station.

Tejon Pass, Cal., April 14, 1918.—A shock was felt at Gorman and Lebec, in the Tejon Pass region, at 11:33 a.m., April 14, 1918. It was observed by several persons. The intensity was about III of the Rossi-Forel scale.

Tejon Pass, Cal., April 17, 1918.—A slight shock was felt in the Tejon Pass region April 17th. The time has not been reported.

Eureka, Cal., April 17, 1918.—Two slight earthquake shocks were felt at Eureka, Cal., April 17th. The first was at 7:48 a.m., lasting fifteen seconds; the second came shortly thereafter. No damage was done.

Port de France, Martinique, W. I.—Slight earthquakes were felt at Port de France, on the island of Martinique, from April 14 to April 18, 1918. Up to the 18th no damage had been done.

San Jacinto, Cal., April 21, 1918.—The earthquake at San Jacinto, Cal., April 21, 1918, is reported upon at length in special articles in this number of the BULLETIN. The intensity reached IX of the Rossi-Forel scale about San Jacinto and Hemet, where considerable damage was done. The same region suffered from an earthquake December 25, 1899. On this last mentioned shock see E. W. Claypole in *American Geologist*, Vol. 25, 106-108, Feb., 1900.

Imperial Valley, California, April 30, 1918.—On April 30, 1918, an earthquake was felt throughout southeastern California and southwestern Arizona. It occurred about 9:35 p.m., and seems to have been most severe in the Imperial Valley. At El Centro people fled from buildings, though no damage resulted. At Calexico some damage was done to a building under construction, and merchandise was thrown from shelves.

Chile, May 20, 1918.—Seismographs at St. Louis, Fordham, New York, Seattle, and Victoria, B. C., recorded a distant earthquake the forenoon of May 20, 1918. It is supposed to have been in Chile. The shocks were renewed May 23d.

Santa Fé, N. M., May 28, 1918.—A shock was felt at Santa Fé, N. M., at 5:30 a.m. It lasted about five seconds, and was strong enough to crack plaster of dwellings.

Los Angeles, Cal., July 22, 1918.—A slight shock is reported by Chas. R. Fletcher at Los Angeles, Cal., about 3:34 a.m. on July 22, 1918.

Stanford University, California, August 3, 1918.—An earthquake was felt at Stanford University, California, August 3, 1918, at 11:30:29 a.m. (Mountain time). The building rattled and the motion was distinctly felt; duration from two to three seconds. Felt by several other persons at rest. Intensity III, Rossi-Forel scale.—S. D. Townley.

REVIEWS

LA SEISMOLOGIA EN MEXICO HASTA 1917, por Manuel Munoz Lumbier. Instituto Geologico de Mexico, Boletin Num. 36.

This report covers the progress of seismological investigations in Mexico up to the year 1917. It contains an excellent summary not only of the work of the government bureaus, but of that of individuals who worked independently in the early days for the love of science.

A summary of the history of the establishment of a seismological service in Mexico was published in the *Boletin Mensual del Observatorio Meteorológico y Seismológico Central de Mexico*, No. 8, August, 1916. This publication was reviewed and summarized in the BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA, 8, 41. A more complete statement of the work of the seismological service appears in the bulletin here under review.

In addition to the history of the work of the Mexican seismologists, the bulletin contains an excellent summary of the general principles of seismology written by Sñ. Teodoro Flores, to which is added a discussion of the seismology of Mexico, accompanied by seven seismological and tectonic maps. This discussion is perhaps one of the best brief summaries of the principles of modern seismology in existence.

The bulletin also contains an interesting chapter on the structure and its relation to the tectonic disturbances of Mexico. The country is divided into nine seismic areas and these are discussed in detail.

In addition to the general discussions, summaries of the results of the study of the more important earthquakes by various commissions and scientists are given, and these furnish seismologists the information they desire for the accurate knowledge of seismic activities in Mexico. Important discussions include: Conclusions in regard to the origin of the earthquakes of Zanatepex, September, 1902, by E. Bose; the origin of the earthquake of the 14th of April, 1907, by E. Bose and A. Villafaña and Jarcía; conclusions in regard to the earthquakes of Guadalajara, by Paul Waitz and Fernando Urbina; study of the earthquake of Acambay, by Fernando Urbina and H. Camacho.

The third part of the report consists of an excellent discussion of the construction and use of seismographs, also the interpretation of

seismographic records. This section of the report also explains the coöperative work of the federal telegraphic service of Mexico, with suggestions as to the expansion of that work by coöperation with other countries.

Part IV is a valuable dissertation in regard to the construction of buildings in seismic zones. The discussion of the construction of wooden buildings is especially valuable, and interesting details of joints, struts, etc., are given. Also it would be well for anyone interested in the study of this country to read this discussion on the construction of earthquake-proof buildings of wood.

This bulletin is one of the most valuable as yet gotten out by the Geological Institute of Mexico on seismic subjects. It is a demonstration of the value of research in seismology now being carried out in the republic of Mexico.

C. F. TOLMAN, JR.

SEISMOLOGICAL OBSERVATIONS IN OSAKA, 1916. Part II of the Annual Report of the Osaka Meteorological Observatory for 1916. Published by the Meteorological Observatory, Osaka, 1917.

This report includes lists of earthquake shocks observed by Omori horizontal pendulums, the monthly earthquake frequency, a discussion of earthquake frequency in relation to positions of origins of shocks, and notes on special earthquakes and pulsatory oscillations. It contains extremely valuable reproductions of seismographic records of important earthquakes and interpretations of these records.

C. F. TOLMAN, JR.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado.—Jesuit Seismological Service, Sacred Heart College. Reports nos. 3 to 6, March 1 to June 30, 1918.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, from January 1 to May 31, 1918.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegio San Calixto (P. P. Jesuitas). Reports nos. 42 to 50, October 5 to December 31, 1917.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory. Reports nos. 4 to 11, March 1 to June 30, 1918.

Washington, D. C.—Seismological Bulletin of the Georgetown University, nos. 35 to 39 bis, February 1 to June 22, 1918, and compiled press dispatches for February, April, and June.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique de l'Observatoire, nos. 2 to 6, from February 4 to May 4, 1918.

EUROPE

Barcelona, Spain.—Estacion Sismica de la Real Academia de Ciencias y Artes. Reports 43 to 47, October 1, 1917, to April 30, 1918.

Coimbra, Portugal.—Boletim Sismico do Observatorio da Universidade, nos. 2 to 4 bis, February 1 to April 30, 1918.

Stonyhurst College, England.—Earthquake Records of the Observatory, from April 2, 1917, to February 25, 1918.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 31 to 40, October 1 to December 31, 1917, and nos. 1 to 6, January 1 to February 28, 1918.

PUBLICATIONS RECEIVED

University of California Publications. Bulletin of the Seismographic Stations, nos. 12 to 14. The registration of earthquakes at the Berkeley station and at the Lick Observatory station, by E. F. Davis. Berkeley, 1917-1918.

Harvard Seismographic Station. Seventh Annual Report, including records. January 1-December 31, 1915. J. B. Woodworth, Cambridge, 1917.

Hawaiian Volcano Observatory. Weekly Bulletin, 4, nos. 5, 6, 7, Honolulu, 1916. No. 2, Honolulu, February, 1918.

Georgetown University Publication. Bulletin of the Seismographic Station. No. 1, pp. 1-23. The registration of earthquakes, etc., etc., from January 1, 1916, to January 1, 1917. By F. A. Tondorf, S. J. Washington, 1917. No. 2, pp. 1-30, from January 1, 1917, to January 1, 1918. Washington, 1918.

"Magnetic results, 1916." By Otto Klotz. Extract, *Journal of the Royal Astronomical Society of Canada*, July-August, 1917.

"The scientific work of the government." By Otto Klotz, Ottawa, 1917.

"Location of epicentres for 1916," by Ernest A. Hodgson. *Journal of the Royal Astronomical Society of Canada*, July-August, 1918.

"Results of observations made at the U. S. Coast and Geodetic Survey Magnetic Observatory near Tucson, Arizona, 1915 and 1916." By Daniel L. Hazard, Washington, 1918. (Earthquakes, pp. 98-100.)

"Results of observations made at the U. S. Coast and Geodetic Survey Magnetic Observatory near Honolulu, Hawaii, 1915 and 1916." By Daniel L. Hazard, Washington, 1918. (Earthquakes, pp. 96-100.)

Boletín Mensual del Observatorio Meteorológico y Sismológico Central de México. Tacubaya, D. F. Enero de 1917, no. 1-Julio de 1917, no. 7.

"Informe presentado al Sr. Ministro de Instrucción Pública sobre la actividad del volcán Irazú," por J. Fidel Tristan y Ricardo Fernández Peralta. 14 pp., ill. San José de Costa Rica, 1917.

"Informe que la Comisión del Observatorio Sismográfico presenta a la Sociedad Geográfica de Lima." 80 pp. Lima, 1908.

Republica Argentina. Oficina Meteorologica Nacional, Jorge O. Wiggan, jefe. *Boletin Mensual*, año II, nos. 2, 3, Febrero, Marzo de 1917. Buenos Aires, 1918.

"Risultati razionali ottenuti da uno studio di investigazione sismica," por Galdino Negri. La Plata, 1914.

"Sobre las constantes de Dutton y de Oldham," por Galdino Negri. *Revista del Centro Estudiantes de Ingenieria*, no. 187. Buenos Aires, 1918.

"Tiempos y velocidades en los calculos sismológicos," por Galdino Negri. *Revista del Centro Estudiantes de Ingenieria*, no. 189. Buenos Aires, 1918.

"La sismologia de los autores clasicos griegos y romanos," and "Observaciones de 1914 y 1915." Por Don Fernando de Montessus de Ballore. *Boletin del Servicio Sismologico de Chile*, 13. Extracto de los *Anales de la Universidad*. Santiago, 1918.

"Bibliografia general de temblores y terremotos," por F. de Montessus de Ballore. Septima Parte. Publicada por la Sociedad Chilena de Historia y Geografia. Santiago, 1917.

"Teremoto del año 1582 en Arequipa, e erupción del volcán Omate en el año de 1600." Por Fernando de Montessus de Ballore. *Revista Chilena de Historia y Geografia*, 24, n. 28. Santiago, 1918.

"Annual Report of the Osaka Meteorological Observatory for the year 1917. Part II, seismological observations in Osaka, 1917." Osaka, 1918.

"Catalogue of Philippine Earthquakes, 1916." Reprint from the *Weather Bulletin* for December, 1916.

"Observaciones Macrosismicas del Observatorio Fabra de la Real Academia de Ciencias y Artes de Barcelona." Hojas num. 3-4 (1917).

"Ensayo de algunas formulas aplicables a los macrosismos," por el P. Manuel M^a. S. Navarro Neumann, S. J. Congreso de Valladolid. Madrid (1915).

Cronistoria dei terremoti Etiopici anteriori all' anno 1913, per L. Palazzo. *Bollettino della Società Sismologica italiana*, 19. Modena, 1915.

"Du rôle comparé des diverses nationalités dans les progrès de la sismologie moderne," par Comte de Montessus de Ballore. Est. dal *Bol. della Soc. Sis. Ital.* 20, Modena, 1916.

"Macrosismi avvertiti in Italia nell' anno 1916." Catalogo compilato da G. Martinelli. Est. dal *Bol. della Soc. Sis. Ital.* 20, Modena, 1916.

"A proposito del terremoto Ligure del 1887," per G. Agamennone. Risposta al F. Porro. Est. dal *Bol. della Soc. Sis. Ital.* **20**, Modena, 1916.

Il Principe B. B. Galitzin, per L. Palazzo. Est. dal *Bol. della Soc. Sis. Ital.* **20**, Modena, 1916.

Bollettino della Societa Sismologica Italiana, **20**, nos. 1, 2, 3, 4, 5, 6. Modena, 1916.

"Rettifiche e considerazioni sulla velocita del terremoto del 13 Gennaio 1915." Nota di G. Agamennone. *Rendiconti della R. Acc. dei Lincei*, **26**. Roma, 1917.

"La velocita di propigazione del terremoto Ligure del 23 Feb. 1887." *Rendiconti della R. Acc. dei Lincei*, **26**. Roma, 1917.

Bollettino Mensile della Osservazioni. Osservatorio Meteorico-Geodinamico "Guzzanti" in Mineo (Sicily). Anno **31**, nos. 11-12. Caltagirone, 1918.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF
THE SEISMOLOGICAL SOCIETY OF AMERICA
MAY 4, 1918.

In the absence of the President, the meeting was called to order by Vice-President Tolman, at 2:15 p.m., at the Engineers' Club, 57 Post street, San Francisco, California. Directors Branner, Lawson, Tolman, and Townley were present.

The minutes of the meeting of the Board of Directors of December 11, 1917, were read and approved.

The report of the Board of Election was read by the Secretary and ordered filed.

After being duly nominated, the following officers were elected for the year:

President	C. F. MARVIN
First Vice-President.....	C. F. TOLMAN, JR.
Second Vice-President.....	OTTO KLOTZ
Third Vice-President	H. O. WOOD
Secretary-Treasurer	S. D. TOWNLEY

The report of the Secretary-Treasurer for the year ending April 6, 1918, was read and ordered filed.

The report of the Auditing Committee was read by the Secretary and ordered filed.

The actions recorded below were taken by the Board:

(a) The following named persons were elected to membership in the Society: F. W. Bunyan, Sacramento, Cal.; Wendall P. Hoge, Mt. Wilson, Cal.; Handforth Hope-Jones, Lima, Peru; G. F. Marsh, Lone Pine, Inyo County, Cal.

(b) The following named institutions were placed on the list of subscribers to the BULLETIN: Indiana University Library, Bloomington, Ind.; Iowa State College, Ames, Iowa; the Director of Meteorological Service, Dept. of Marine and Fisheries, Toronto, Ontario, Can.; Mount Wilson Solar Observatory, Solar Observatory Office, Pasadena, California; University of British Columbia Library, Vancouver, B. C.

(c) The Secretary reported the resignation of George C. Branner, W. S. Franklin, C. W. Henderson, W. H. Hobbs, E. M. Keyser, B. C. Ledyard, H. L. Middleton, Oakland Free Library, F. B. Peck, George O. Smith and George O. Spencer; the death of A. H. Purdue and D. G. Scofield; and the dropping of fourteen members for the non-payment of dues.

(d) The Secretary reported that a grant of \$250, for the year 1918, had been made to the Society by the Committee on Grants of the American Association for the Advancement of Science, for the investigation of earthquakes. The

grant was accepted by the Board, and the Secretary instructed to write a letter of appreciation to the Chairman of the Committee.

(e) It was decided to use the grant of \$250 for a thorough investigation and mapping of the San Jacinto fault, provided it is possible to find the right man for the work.

(f) The sum of \$100 was appropriated from the General Fund to cover the expense of the investigations of the San Jacinto earthquake of April 21, 1918, carried out by Homer Hamlin and S. D. Townley.

(g) The salary of the Secretary-Treasurer was continued at the rate of \$20 per month for the fiscal year 1918-19.

Adjourned 3:45 p.m.

S. D. TOWNLEY, *Secretary*.

REPORT OF THE BOARD OF ELECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA

San Francisco, Cal., April 6, 1918.

President and Members of the Seismological Society:

We, the undersigned judges of election, certify that 108 ballots were cast at the annual election, held in San Francisco on this date, with the following result:

Bernard Benfield	33	J. K. Moffitt.....	41
J. C. Branner.....	106	A. H. Palmer.....	41
W. W. Campbell.....	97	H. F. Reid.....	82
E. F. Davis.....	38	R. W. Sayles.....	56
R. S. Holway.....	44	C. F. Tolman, Jr.....	89
Otto Klotz	63	S. D. Townley.....	103
A. C. Lawson.....	94	B. M. Varney.....	22
A. G. McAdie.....	83	H. O. Wood.....	80
C. F. Marvin.....	89	J. B. Woodworth.....	85

The following named, being the twelve receiving the highest number of votes, are declared elected directors of the Society for the year 1918-19:

J. C. Branner	J. B. Woodworth
S. D. Townley	A. G. McAdie
W. W. Campbell	H. F. Reid
A. C. Lawson	H. O. Wood
C. F. Marvin	Otto Klotz
C. F. Tolman, Jr.	R. W. Sayles

R. S. HOLWAY,
FRANK V. CORNISH,
BERNARD BENFIELD,
D. S. RICHARDSON,
Board of Election.

REPORT OF SECRETARY-TREASURER

From April 7, 1917, to April 6, 1918.

The total number of members of the Society and subscribers to the BULLETIN is now 408, exactly the same as at the time of my last report a year ago. Five members were lost through death: Richard E. Call, New York, N. Y.; John T. Fogarty, San Francisco, Cal.; George W. Riter, Salt Lake City, Utah; R. H. Loughridge, Berkeley, Cal.; A. H. Purdue, Nashville, Tennessee.

The Santa Barbara Channel earthquakes of April, 1917, were investigated by the Society and the report published in the June number of the BULLETIN. This work was made possible through a generous gift from Dr. J. C. Branner.

Volume 7 of the BULLETIN, containing 163 pages and twelve plates, was issued during the year 1917.

The financial report is as follows:

<i>Dr.</i>		GENERAL FUND	
To balance, April 7, 1917.....	\$	102.33	
Dues and subscriptions		790.73	
Reprints		13.70	
Sale of publications		36.00	
Gifts from J. C. Branner		70.65	
Transfer from Sayles Fund, interest.....		235.00	
Transfer from Life Membership Fund, interest.....		21.60	
Total		\$1,270.01	
<i>Cr.</i>			
By Stanford University Press, printing Vol. 7, Nos. 1 and 2.....	\$	288.10	
Stanford University Press, reprints		28.70	
Stanford University Press, miscellaneous printing.....		1.50	
Stanford University Press, manila envelopes.....		8.00	
Times Publishing Co., printing Vol. 7, Nos. 3 and 4.....		230.05	
Times Publishing Co., reprints		13.90	
Times Publishing Co., manila envelopes.....		9.50	
Leland Stanford Junior University, miscellaneous printing.....		6.25	
Commercial Art Co., illustrations.....		42.15	
Second class postage on BULLETINS		4.66	
Foreign postage on BULLETINS		8.07	
Stamped envelopes		21.60	
A. C. Mattei, investigation of Santa Barbara Channel Earthquakes		67.65	
Miscellaneous postage		13.50	
Express		1.20	
Rent safety deposit box.....		2.00	
W. F. Loel, drawings.....		3.00	
J. L. Vincenz, drawings		3.00	
S. D. Townley, salary Secretary-Treasurer.....		240.00	
Balance, April 6, 1918.....		277.18	
Total		\$1,270.01	

LIFE MEMBERSHIP FUND

Dr.

To balance, April 7, 1917.....	\$ 525.00
Three life memberships	75.00
Interest from Berkeley Bank of Savings and Trust Co.....	21.60
Total	\$ 621.60

Cr.

By interest, transferred to General Fund.....	\$ 21.60
Balance, April 6, 1918.....	600.00
Total	\$ 621.60

SAYLES FUND

Dr.

To balance, April 7, 1917.....	\$4,000.00
Interest from Mutual Building and Loan Association of San Jose and College Park	55.00
Interest from Palo Alto Mutual Building and Loan Association....	120.00
Interest from Truckee Lumber Co.....	60.00
Total	\$4,235.00

Cr.

By transfer to General Fund, interest	\$ 235.00
Balance, April 6, 1918	4,000.00
Total	\$4,235.00

S. D. TOWNLEY,
Secretary-Treasurer.

REPORT OF THE AUDITING COMMITTEE

The books of the Seismological Society of America were submitted to the Auditing Committee of the Society by Secretary-Treasurer Townley, on the 3d day of May, 1918, the period to be audited being from April 7, 1917, to April 6, 1918.

1. All expenditures were substantiated by properly receipted bills.
2. Membership cards, showing dues received during the year, were found to be properly credited in the General Fund.
3. All book entries were checked and found to be correct.

The balances in the various accounts on the 6th day of April, 1918, were as follows:

General Fund	\$ 277.18
Life Membership Fund.....	600.00
Sayles Fund	4,000.00
Total.....	<u>\$4,877.18</u>

Attention is called to the fact that the stock certificates of the Mutual Building and Loan Association of San Jose, Palo Alto Mutual Building and Loan Association, and the bond of the Truckee Lumber Company were not submitted to the Auditing Committee.

OTTO VON GELDERN,
J. K. MOFFITT,
Auditing Committee.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

- I. **Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. **Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. **Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. **Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. **Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. **Fairly strong shock:** general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.
- VII. **Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. **Very Strong shock:** fall of chimneys, cracks in walls of buildings.
- IX. **Extremely Strong shock:** partial or total destruction of some buildings.
- X. **Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

Bulletin of the Seismological Society of America

PUBLICATION COMMITTEE

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ANDREW C. LAWSON, Berkeley, Cal.

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DECEMBER 1918

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The Bulletin of the Seismological Society of America

VOL. VIII

DECEMBER, 1918

No. 4

THE VIRGINIA EARTHQUAKE OF APRIL 9, 1918.¹

By THOMAS L. WATSON

In the evening of April 9, 1918, middle and northern Virginia were feebly, though sensibly, shaken by an earthquake that was felt in the District of Columbia, over parts of West Virginia and Maryland, and in at least one locality in Pennsylvania. Reports indicate that the earthquake was general throughout the Shenandoah Valley in Virginia and northward through the Cumberland Valley in Maryland. Records were obtained on the seismographs at Washington, D. C. (intensity III-IV of the Rossi-Forel scale), and the shock was of sufficient intensity to be registered by the instruments at Cornell University, Ithaca, N. Y., and at Harvard University, Cambridge, Mass.²

It is not possible from the meager data to make an accurate estimate of the total area over which the shock was felt, but it was probably not less than sixteen thousand square miles in Virginia. The extreme points from which reports were received are Colebrook, Berks County, Pa., about sixty miles northwest of Philadelphia, on the north; Danville, Va., about four miles north of the Carolina boundary, on the south; Williamsburg, Va., forty-eight miles east of Richmond, and Solomons, Md., near the confluence of Patuxent River with Chesapeake Bay, seventy-five miles north of Williamsburg, Va., and sixty miles southeast of Washington, D. C., on the east; Roanoke City, in the Valley of Virginia, on the southwest; and Buckhannon, Upshur County, W. Va., in the Appalachian Plateau, on the west.

¹ The information regarding the earthquake was obtained from various sources, but chiefly from questionnaires sent out by the writer shortly after the occurrence of the shock, from newspaper accounts, and from Dr. W. J. Humphreys of the U. S. Weather Bureau, Washington, D. C., who generously furnished data reported by the Bureau's many coöperative observers.

² In a personal communication to the writer Professor Woodworth states that the Harvard record was very poor.

Excluding the Appalachian Valley Ridges and the Appalachian Plateau to the west, the shock was felt in each of the physiographic provinces of Virginia and Maryland, including in Virginia the western part of the coastal plain as far south as Richmond and east to Williamsburg, the entire length of the Piedmont Plateau from the Potomac to Danville on the south; over the northern and middle Blue Ridge; and the great valley as far southwest as the city of Roanoke. (See map, Plate I.) A report from Buckhannon, Upshur County, W. Va. (intensity II R.-F. scale), indicates that the shock was felt in the Appalachian Plateau province west of the valley ridges.

Over most of the region the shock was slight—very feeble to feeble in intensity (II to IV of the Rossi-Forel scale). In the northern Shenandoah Valley region of Virginia and northward for a short distance into West Virginia and Maryland, where the intensity was greatest, the shock was of moderate (V) to fairly strong (VI) intensity. It was the severest shock felt in the Shenandoah Valley since the Charleston earthquake of August 31, 1886, and it exceeded the latter in intensity at several places. Practically no damage was done, but the people in many places over the northern valley region were greatly alarmed and some were so badly frightened that they rushed from their houses. One account states that “consternation in some quarters assumed almost a panic, women fainting, . . . etc.” Most of the reports agree that houses were shaken more or less violently, and loose objects, such as dishes and windows, etc., rattled, accompanied in many places by loud noises.

The time of the shock recorded at the Georgetown University Seismological Observatory, West Washington, D. C., was 1^h 9^m 12^s Greenwich Mean Time. Naturally the non-instrumental reports as to the time of the shock differ considerably, the best estimate being between 9:09 and 9:10 p.m. (Eastern Time), which is in agreement with the writer's observation in his home at the University of Virginia, where the shock was distinctly felt.

Newspaper accounts published the next morning, April 10, 1918, and subsequent reports gathered by the writer over most of the affected region, indicate that only slight actual damage resulted, confined chiefly to the Shenandoah Valley region, where the intensity was highest. The glass in windows of houses was broken and in several localities the plaster of the ceilings in residences was badly cracked. A report from Clear Spring, Washington County, Md., to the

Weather Bureau, reported five panes of glass broken. Director Tondorf reports that windows were broken in the Georgetown Hospital, which is about three hundred yards distant from the seismological observatory. This is the only point beyond the limits of the great valley from which even the slightest damage was reported as a result of the shock.

The *Page News and Courier*, of May 31, 1918, published at Luray, Page County, Va., states that the earthquake opened a strong spring near Hamburg. Since that time a strong spring has been bubbling up almost in the middle of the road. The water is cold and very clear and strongly impregnated with calcium carbonate derived from limestone, the principal rock in that locality. The present spring has all the appearance of being unfailing. Special inquiry by the writer failed to indicate any surface modification in any part of the affected region, such as opening of fissures or cracks, stream changes, etc. Newspaper accounts mentioned the falling of trees in two localities, but in each case the destruction was due undoubtedly to the strong winds prevailing at the time and not to the earthquake.

From a total of fifty-two reports received from Virginia, thirty-nine reported one shock, nine reported two shocks, and two reported three shocks. In the Shenandoah Valley province two shocks were reported at Berryville, Dale Enterprise, Front Royal, Luray, Harrisonburg, and Staunton; and in the Piedmont Plateau, at Gordonsville, New Canton, and Rapidan. At Luray and Winchester the first shock occurred about 9:10 p.m., April 9, 1918, and the second about 2 a.m., April 10, 1918. Several reports received from Winchester indicated that the second shock was equal in intensity to the first. At Harrisonburg, Dale Enterprise, and Staunton the two shocks were separated by an interval of only a few minutes. At Highland Park, a suburb of Richmond, and at Culpeper, near the western margin of the Piedmont Plateau, three distinct shocks were reported. Under date of April 16, 1918, the Luray paper published the statement that northern Virginia was visited again on that date by another earthquake at 8:40 a.m., the fifth within a week at Luray.

The duration of the shock recorded at the Georgetown University Seismological Observatory was 4^m 16^s. The period may possibly have been shorter, since Director Tondorf stated that the end was not quite certain because of being lost in heavy wind markings. There was necessarily considerable variation in the observational reports as to the

duration of the shock, the range being from one second to five minutes. The best average, estimated by the writer from a study of the reports received, gives a probable duration of thirty to forty-five seconds.

About 45 per cent of the observers report having heard a noise or sound which either preceded or accompanied the shock. The sound or noise was variously described as "rumbling," "a hoarse rumbling," "like distant or low thunder," "running of a heavy motor truck with exhaust open," "an auto with the cutout open," "running of a heavy railroad train," "a train running beneath the house at some depth," "a heavy or violent wind," "a giant explosion," "a loud explosion," etc. A study of the reports discloses the fact that the places at which a sound was heard were not confined to any particular part of the region affected by the shock, but were heard in the Shenandoah Valley, the northern Blue Ridge, the Piedmont Plateau, and the Fall Belt. However, much the largest number of places at which sounds were heard was located within the Shenandoah Valley region and was nearly double the total number of places over the rest of the affected region.

The non-instrumental or observational data are summarized in Table I, with the columns of duration, sounds, and observer purposely omitted.

Plate 16 is a physiographic map of a part of Virginia on which is marked the intensity of the shock at each of the more important places from which reports were received. The observational or non-instrumental data are given in Table I. No attempt has been made at drawing isoseismals on the map because of the incompleteness of data. Attention is directed, however, to the fact that not a single report was received by the writer of the earthquake having been felt in the Valley Ridges subprovince of folded Paleozoic sedimentary rocks immediately west of the Shenandoah Valley subprovince, the region of highest intensity. On the other hand, the shock was distinctly felt (highest intensity IV-V, R.-F. scale) over the region of crystalline rocks (including the Blue Ridge and Piedmont Plateau) on the east side of the Shenandoah Valley, and still farther east over parts of the coastal plain (intensity I-IV, R.-F. scale). More complete investigation would undoubtedly discover persons in the Valley Ridges subprovince who felt the shock, since it was reported felt at Buckhannon, Upshur County, W. Va., (II, R.-F. scale), which town is located some distance west of the valley ridges subprovince well within the Appalachian Plateau of nearly flat-lying sedimentary rocks.

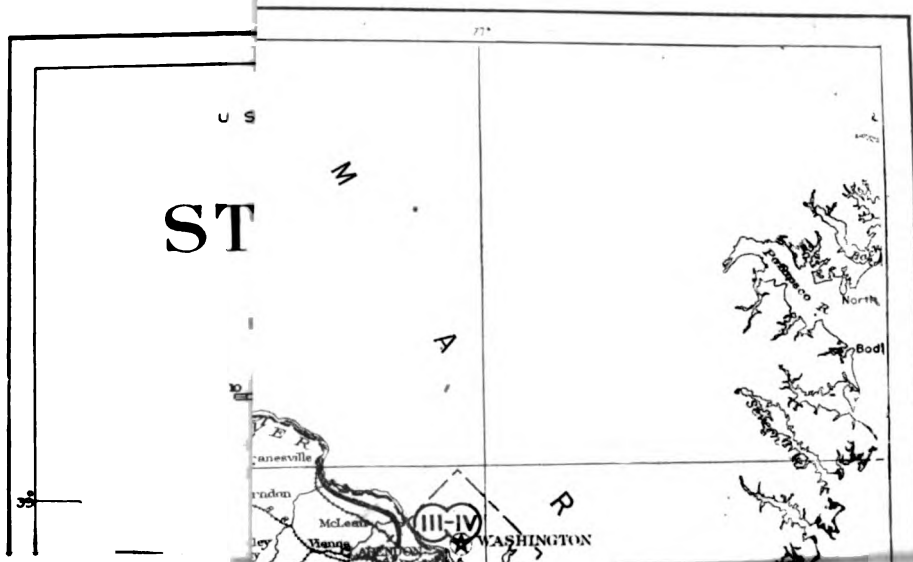




TABLE I. NON-INSTRUMENTAL EARTHQUAKE REPORTS, 1918.

Station.	Approximate N. Latitude.	Approximate W. Longitude.	Intensity R.-F. Scale.	No. of Shocks.	Remarks.
DISTRICT OF COLUMBIA					
Washington	38°54'	77°03'	3	1	Gradual trembling. Windows were broken in Georgetown University Hospital.
MARYLAND					
Bagley	39 30	76 23	1	1	Gradual trembling.
Baltimore	39 17	76 37	2	1	
Chewsville	39 30	77 37	4	1	Gradual trembling S.W.-N.E.; like blasting.
Clear Spring?	39 37	77 55	..	..	Five panes of glass found broken.
College Park.....	38 58	76 55	3	1	
Solomons?	38 19	76 27	4?	1?	Abrupt trembling with slight rumbling.
Takoma Park	38 58	77 01	3	1	
Woodstock	39 19	76 55	2	1	Gradual trembling.
PENNSYLVANIA					
Colebrook	40 26	76 04	2	1	Gradual trembling.
VIRGINIA					
Alexandria	38 48	77 03	3	1	Rain accompanied by high winds lessened the effects of the shock. Country for miles around was shaken for more than 3 minutes.
Arvonnia	37 41	78 21	3	1	Abrupt trembling.
Berryville	39 09	77 59	5	2	Sounded like an auto with the cutout open.
Brookneal	37 05	78 55	2	1	Slight shock; felt by only a few people.
Buchanan	37 32	79 41	1	1	Gradual trembling.
Castleman's Ferry	39 07	77 59	3-4	1	Sounded like low thunder.
Charlottesville ..	38 02	78 28	3	1	Abrupt trembling; rumbling like low thunder.
Chatham	36 45	79 26	1	1	
Columbia	37 45	78 13	3	1	Sounded like a violent wind.
Culpeper	38 29	77 59	4	3	Abrupt rocking.
Dale Enterprise..	38 27	78 55	3	2	Abrupt trembling; rumbling.
Danville	36 34	79 26	2	1	Gradual rocking.
Edinburg	38 49	78 34	6	1	Rumbling noise that increased the fear of many. Ceilings in houses were badly cracked.
Farmville	37 18	78 24	3	1	Very distinct. Houses were shaken and windows rattled.
Fredericksburg	38 18	77 28	3	1	Rumbling sound.
Front Royal.....	38 55	78 11	4	2	Noise likened to a loud explosion.

TABLE I.—*Continued.*

Station.	Approximate N. Latitude.	Approximate W. Longitude.	Intensity R.-F. Scale.	No. of Shocks.	Remarks.
Gordonsville	33° 18'	78° 11'	3	2	Rapid trembling.
Guinea	38 09	77 26	1	1	Gradual trembling W.-E.
Harrisonburg	38 25	78 52	5	2	A hoarse rumbling noise. S. to N. and N.E. Glass in windows broken.
Highland Park..	37 34	77 25	3	3	Houses severely shaken for several seconds.
Lantz Mills	38 51	78 36	5	1	Rumbling most uncanny. Chandeliers swung like pendulums.
Leesburg	39 07	77 34	4	1	No appreciable noise.
Lexington	37 48	79 26	3	1	Rumbling sufficient to cause children to ask what it was.
Louisa	38 02	78 00	4	1	Noise like tin being torn from the roof of a house. One or two people awakened from sleep.
Luray	38 41	78 27	5	2	Likened to a giant explosion. Felt throughout Page County.
Lynchburg	37 25	79 09	2	1	Gradual trembling. Shock felt in the contiguous counties.
Madison C. H....	38 23	78 15	4	1	Distinct rumbling noise from the N.W.
Manassas	38 45	77 28	3	1	Abrupt trembling.
Mineral	38 01	77 54	3	1	Noise similar to distant thunder. N.E.
New Canton	37 43	78 18	4	2	Abrupt trembling.
New Market	38 39	78 40	4	1	Rumbling noise like thunder.
Orange	38 15	78 07	4	1	Abrupt rocking, rumbling.
Palmyra	37 52	78 16	3	1	
Purcellville	39 08	77 43	4	1	No appreciable noise.
Rapidan	38 19	78 04	3	2	Gradual trembling.
Richmond	37 32	77 26	3	1	Gradual rocking N.W.-S.E.
Riverton	38 57	78 11	4	1	
Roanoke	37 16	79 56	2	1	Gradual rocking.
Stafford	38 26	77 24	3-4	1	No appreciable noise.
Staunton	38 10	79 04	4	2	Gradual trembling N.E. S., rumbling. Glass in some windows broken. Surrounding country violently shaken.
Tenth Legion	38 35	78 43	4	1	Rumbling noise like thunder.
Timberville .....	.....	.....	4	1	Rumbling noise like thunder.
Top of Blue Ridge (E. of Castleman's Ferry)	39 07	77 50	4	1	Sounded like a heavy wind.
Trevilians	38 03	78 03	4	1	Noise similar to "a train running beneath the house at some depth."

TABLE I.—*Concluded.*

Station.	Approximate N. Latitude	Approximate W. Longitude	Intensity R.-F. Scale	No. of Shocks	Remarks.
University	38° 02'	78° 31'	3	1	Abrupt trembling S.W.-N.E.; rumbling like heavy thunder.
Warrenton	38 43	77 48	3	1	Distinctly felt and heard; caused but little alarm and no damage.
White Post	39 04	78 07	4	1	Abrupt trembling, rumbling like running of heavy motor truck with the exhaust open. Plaster in houses cracked. Similarly felt throughout Frederick County.
Williamsburg	37 16	76 42	2	1	
Winchester	39 10	78 10	5	1	
Woodbury For- est (School) ..	38 17	78 08	3	1	
Woodstock	38 53	78 31	5	1	No noise. Gradual trembling E.-W., rumbling like running of a heavy railroad train.
WEST VIRGINIA					
Buckhannon	38 59	80 15	2	1	Gradual trembling.
Martinsburg	39 28	77 58	5	1	Gradual bumping, runbling.

NEWSPAPER ACCOUNTS FROM THE SHENANDOAH VALLEY, VIRGINIA

Most of the newspapers published within the limits of the region affected by the shock carried prompt but in most cases very brief accounts of the earthquake. In the valley region, where the shock was the severest, the newspaper accounts were more complete and instructive. This was especially true of the account published by the *Winchester Evening Star*. Descriptions published in several of the valley papers are given below:

Winchester.—The *Winchester Evening Star* of April 10, 1918, carried a very full statement of the occurrence of the earthquake in that locality on the evening of April 9. The statements which follow below are quoted from the account published in the above paper:

Winchester experienced last night its first real earthquake shock, which occurred at 9:10 o'clock during a howling blizzard which was raging. . . . In this city the experiences of citizens were very much the same. The shock resembled the effect produced by the vibration of heavy machinery, while the rumbling was of the volume of a heavy motor truck running with the exhaust

open. In many homes the inmates rushed into the blizzard which was raging at the time and great excitement prevailed everywhere.

Some hundreds of calls began going over the phone from inquirers asking the cause of what appeared to be a long continuous explosion. The quake lasted only about twenty seconds, but it seemed to many persons to be about that many minutes.

A series of unusual occurrences locally were coincident with the earthquake shock. Shortly after the quake all of the electric lights in Winchester went out and the city was in total darkness until daylight. The town clock stopped during the night, and the darkness, with the wind howling and a blizzard prevailing with six inches of snow falling, with a severe earthquake, all served to spread terror in many minds.³

When the shock took place at 9:10 o'clock very few people had retired for the night. The shock began with a loud rumbling which caused even the largest brick buildings in the city to tremble as though some heavy machinery had been installed and was running at high speed with great vibration. At the same time the noise exactly resembled the efforts of some motor truck to extricate itself from a stalled position, the loud rumbling seeming to be located in the houses and the volume of sound being about equal to a large automobile running with its exhaust open.

The shock and noise continued for perhaps fifteen seconds, and then dying down was succeeded by sharp explosions, and then the sound grew gradually fainter until at the end of twenty seconds' time—which seemed, however, to the terror-stricken people like an age—the houses ceased to rock, the murmurings of the earth died away, and people began to gather their wits and seek the cause, and, in some instances, to seek safety in flight from their homes.

The experiences of hundreds were alike in every detail, the comparison of the automobile exhaust being used by many to illustrate the sensation of the quake.

Those persons who have furnaces in their homes rushed to their cellars to see if the boilers had exploded. Others thought their water pipes had burst, while many others thought the noise and the rocking of houses was due to the series of blasts from faraway rock quarries.

Many people ran from their homes and sought refuge in the homes of neighbors, glad of the comfort which companionship afforded. Many others, terror-stricken at their experiences, refused to go to bed again, but sat up throughout the night.

Later on those who sat up were denied even the comfort which light afforded them, because the entire electric light system ceased to function about midnight and the city was in darkness until daylight.

³ Neither the failure of the electric lights nor the stopping of the town clock around midnight could be attributed to the earthquake, since the first and principal shock occurred nearly three hours earlier and the reported second shock at least an hour later than the time of failure of the lights and clock.—T. L. W.

From some unexplained cause the big town clock on top of the city hall stopped some time after midnight, but it is not thought that this had anything in common with the earthquake.

Little details of how far-reaching the earthquake was could be obtained today, because of the fact that the telegraph wires were all down in many directions, particularly those wires coming into Winchester. It was learned, however, that while the quake was widespread throughout the east, little actual damage resulted.

In Winchester the plaster on walls was cracked, lighted lamps were rocked and nearly upset by the vibrations, while dishes were rattled and every house was rocked on its foundations as though it had been seized by some giant hand and shaken like a dog shakes a rat.

Last night's shock was the most violent ever experienced in this section, and coming as it did, during the prevalence of an unusually severe wind and snow storm, it caused alarm and terror in almost every breast.

Out in Frederick County the experiences were the same as in town. Many people called up Winchester to learn the cause of the shock and also called up neighbors on the phone to learn if the latter had also had a like experience. The loud noise seemed to be coming from every room in the house, but a search could not disclose the source. At the moment few persons had thought they were passing through a severe earthquake shock, and all seemed bent on locating some reasonable theory for the thing, but when none could be found, then terror for the first time seemed to seize them.

Many alarming reports as to damage done in this section have been received by *The Star* today. For instance, it was stated that the quake had opened up huge chasms in the mountains of Warren County, causing the earth to roll down on the Norfolk & Western Railroad tracks, blocking traffic.⁴

An investigation disclosed that last night the high wind blew a large tree across the tracks, stopping several trains until the tree could be removed.

Many people in Winchester today declare that a second earthquake shock occurred at 2 o'clock this morning which equaled in intensity the first shock at 9:10 last night.

Luray.—The *Page News and Courier* of April 12, 1918, published at Luray, carried the following description of the earthquake on the evening of April 9:

The severest earthquake shock ever felt in this latitude was felt all over Page County Tuesday night at 9 o'clock. On account of the heavy snow falling at the time nearly everybody was indoors, which intensified the fear of all who felt the quake. In some parts of Luray the shock is said to have been so severe as to knock people from their chairs. Many people were badly frightened, some of them being restrained from jumping from upstairs windows. For

⁴ As stated elsewhere in this paper the writer, upon careful inquiry, was unable to obtain any evidence that the earthquake opened chasms in Warren County or in any other part of the affected region, or that it caused earth-slides.—T. L. W.

some time it did not dawn on our people what the trouble was, some thinking it was a giant explosion. Houses swayed and windows rattled and consternation in some quarters assumed almost a panic, women fainting and having to be revived by artificial means.

The night, a sleepless one to many, saw another shock between 2 and 3 o'clock on Wednesday morning. This was of short duration, though the shock was of sufficient force to be unmistakable. All in all, the night will be handed down to succeeding generations as a very eventful one in the history of the Valley of Virginia.

Under date of April 16, 1918, the same paper reported that northern Virginia was visited again on that date by another earthquake shock at 8:40 a.m., the fifth within a week at Luray, when people indoors ran to the streets. The statement adds that buildings rocked and windows rattled.

Harrisonburg.—The *Daily Independent* of April 10, 1918, of Harrisonburg, carried the following account of the earthquake on Tuesday evening:

For the first time in her history Harrisonburg and the Shenandoah Valley last night at exactly 9:08 o'clock experienced a distinct earthquake shock.

In Harrisonburg the shock was felt when a hoarse rumbling was heard as if coming from the very depths of the earth. Apparently the tremor was from south to the north and northeast. Buildings were shaken and windows were caused to rattle violently. Timid people were frightened and several telephone calls were answered by the *Daily Independent* last night from persons who wished to know what had happened.

WEATHER CONDITIONS

Especial attention is directed to the weather conditions at the time of occurrence of the earthquake on account of prevalent winds of high velocity over most of the region affected by the shock, which undoubtedly affected the accuracy of observations at the time in many places.

During the day of the earthquake and the one following the weather conditions were generally stormy over the region affected by the shock. It was prevailingly cloudy with rain or snow falling over much of the region affected, accompanied by winds of high velocity. Over much of the Shenandoah Valley region a blizzard (unusually strong wind accompanied by a nearly blinding heavy snowfall) was raging at the time of the occurrence of the earthquake. Early fruit trees (peaches, plums, etc.) were in full bloom, and the ground was covered with snow to a depth of ten inches in places, which drifted to such an extent as to make roads impassable.

Dr. P. C. Day, chief of the climatological division of the Weather Bureau, Washington, D. C., kindly furnished the writer with a rough copy of a manuscript chart prepared at his office showing weather conditions at 8 p.m., April 9, 1918, about one hour before the earthquake occurred. The chart shows a well developed area of a deep "low" centered at Hatteras off the Carolina coast, with steep isobaric gradients to the south, southeast, and east, on the north and west sides of the "low." Range in temperature over most of the region affected by the shock was from 30 to 40 degrees, and in pressure from 30.2 to 29.9. Comparing this chart with the map published twelve hours later (8 a.m., April 10, 1918), the "low" had diminished in intensity and had moved north and west to a position between Norfolk and Richmond, Va.

SUMMARY OF GEOLOGY AND CONCLUSIONS

Since, from the reports received, the shock seems to have been most severe in the northern part of the Valley of Virginia, a very brief summary of the geology of the northern valley region is of some interest in seeking the probable cause of the earthquake. The Valley of Virginia is bounded on the southeast by the Blue Ridge, the central portion of which is composed of pre-Cambrian igneous rocks and on the northwest by the Valley Ridges subprovince of folded sedimentary rocks ranging up to Devonian and Mississippian in age.

The valley maintains an approximate width of twenty miles from the state boundary southwestward to nearly the latitude of Greenville, Augusta County (Map, Plate I). From near the latitude of Strasburg and Riverton to that a short distance south of Harrisonburg, the valley is divided lengthwise by Massanutten Mountain, which is synclinal in structure and composed of sedimentary rock ranging up to and including Devonian in age. The mountain extends southwestward for a distance of about forty-five miles, and divides the valley lengthwise into two narrow valleys which average from five to ten miles in width. The Massanutten syncline, however, which involves the Martinsburg shale (Ordovician) at the surface, continues for a considerable distance both to the northeast and to the southwest of the north and south ends of the mountain proper.

The valley bottom is developed on folded limestone and shales of Cambro-Ordovician age, underlain by quartzites, sandstones, and shales of Lower Cambrian age which, because of their structure and

greater resistance, are exposed along the northwest flank of the Blue Ridge. No igneous rocks are known to occur in the valley proper north of the latitude of northern Rockingham County.

The valley rocks are faulted, but in some localities at least the faulting appears to be slight, since the displacement is frequently not great enough to cut one or more formations. Bassler has recognized faulting at Winchester, one of the localities of highest intensity (VI R.-F. scale), during the earthquake of April 9, 1918. He says:⁵ "Although the full geologic structure in the vicinity of Winchester could not be determined because of lack of continuous exposures, the quarries and other outcrops just west and east of the town indicate that by faulting a band of Lower Ordovician dolomitic limestones has been interpolated between a band of Stones River limestones on the west and argillaceous limestones and shales of Chambersburg and Martinsburg age on the east."

Faulting occurs at the base of Little North Mountain along the northwest side of the valley, and along the northwest front of the Blue Ridge on the southeast side of the valley a great overthrust fault, which apparently follows the Blue Ridge, has a horizontal displacement in places of at least four miles.

It seems probable, therefore, that the seismic disturbance of April 9, 1918, had its origin in one or more of the faults which characterize the region.

University of Virginia

⁵Bulletin II-A, Virginia Geological Survey, 1909, p. 69.

THE RELATION BETWEEN SEISMIC AND MAGNETIC DISTURBANCES

By D. L. HAZARD,

Chief, Division of Terrestrial Magnetism, U. S. Coast and Geodetic Survey.

Even before the time of self-registering magnetic instruments, there were numerous reported cases of compasses or suspended magnets being disturbed at the time of an earthquake. In 1828, for example, an engineer in a coal mine near Mulheim, Germany, at a depth of 410 feet, found it impossible to use his compass needle during a period of fifteen or twenty minutes. On coming to the surface he learned that a heavy earthquake had been felt during the time his needle had been disturbed. On April 18, 1842, Lamont at Munich observed a magnet swinging as if it had been struck a sudden blow, the time coinciding closely with that of an earthquake in Greece. Such cases were necessarily isolated, however, as it was purely a matter of chance that the observer happened to be using the compass at the time of the earthquake, and no definite information was supplied as to the relation between the two phenomena.

There are some early reports, also, of large changes in the magnetic elements at the time of an earthquake. On November 4, 1799, at Cumana, in South America, Humboldt observed that while the declination and horizontal intensity were apparently unchanged by the earthquake, the dip was diminished 48', and then slowly recovered its former value. Again in October, 1802, he observed at Lima that a needle made 219 swings in ten minutes before an earthquake and 213 swings in ten minutes after, indicating a decrease of five per cent in horizontal intensity. The dip before the earthquake was $9^{\circ} 35'$ and after was $9^{\circ} 7'$. Without more details, it is impossible to tell whether these apparent changes in the earth's magnetic field were caused by the earthquake or not. Modern investigations in connection with magnetic surveys in Japan have not developed any such changes, and observations at repeat stations in California, before and after the earthquake of 1906, do not show any unusual change in the magnetic elements.

After the introduction of self-recording variometers, giving a continuous photographic record of the variations of the earth's magnetic elements, it was noted from time to time that the magnetograms at different observatories showed a peculiar disturbance at the time of an earthquake, even at a considerable distance from the origin of the shock. It was not until about thirty years ago, however, that the question of the relation between seismic and magnetic disturbances was given serious consideration. The Riviera earthquake of February 23, 1887, was recorded by most of the magnetographs of Europe and gave rise to much speculation as to the manner in which the disturbance of the instruments was produced, whether mechanical, magnetic, or electrical.¹ The fact that the disturbance was not recorded simultaneously at all of the observatories and appeared later as the distance from the source of the disturbance increased, pointed strongly to the conclusion that the effect recorded was mechanical. It was not clear, however, how a shaking of the ground could cause the oscillations of a suspended magnet. Moureaux thought to decide whether the effect was mechanical or magnetic by setting up on the pier supporting the horizontal intensity magnet, at Parc St. Maar, a copper bar of the same form and size mounted in the same way and with the same orientation. At the time of subsequent earthquakes, the magnet oscillated but the copper bar did not and Moureaux and Mascart thought that this result precluded a mechanical explanation of the phenomenon. As will be seen later, the fact that the magnet oscillated while the copper bar did not was due only indirectly to the magnetic property of the magnet. At Perpignan the Riviera earthquake was recorded on the magnetograph at 5^h 47^m p.m. At 6 p.m. observations of the direct eye-reading apparatus were made and it was noted that the magnets were bobbing up and down but were not moving horizontally. Two and a half hours later, while making oscillation observations, it became necessary to discontinue because of the vertical bobbing of the magnet. The observer at once went to the eye-reading apparatus, and found that there also the magnets were bobbing up and down. This time corresponded with the third shock of the Riviera earthquake.

Another feature which added to the difficulty of the problem was the fact that not all of the magnets at the different observatories were disturbed at the time of an earthquake. At some observatories no change at all was noted, while at others some of the magnets were

¹ *Comptes Rendus*, 104, 1887.

disturbed and others were not. At that time there were not many seismographs in operation, so that a comparison with the seismograph records was not in general possible. After that time the phenomenon was noted on many occasions and the problem engaged the attention of many magneticians, who in general concluded that the oscillations of the magnet were due to mechanical vibrations, basing their conclusion on the fact that the magnets were affected at the time of the arrival of the principal portion of the earthquake vibrations as recorded by the seismographs.

In 1898 John Milne,² hoping to throw light on the subject, prepared a list of large earthquakes recorded by seismographs at widely distributed observatories from 1889 to 1897, and sent it to various magnetic observatories with a request that the magnetograms for the specified times be examined for possible earthquake effects. A study of the reports received leads to the conclusion that most of the observers reported ordinary magnetic disturbances, such as can usually be found within a few hours of any specified time. The results were so inconclusive that Milne considered that it would be necessary to have records from a seismograph and magnetograph operated at the same place in order to secure definite results.

Records of this nature have since become available by reason of the installation of seismographs at a number of magnetic observatories. In North America this has been the case at Toronto since 1897; at Cheltenham, Md., since December, 1904; at Vieques, P. R., since September, 1903; at Sitka, Alaska, since April, 1904; at Tucson, Arizona, since September, 1910. In April, 1903, a Milne seismograph belonging to the British Association was transferred from the Oahu College to the Honolulu Magnetic Observatory.

In 1904, J. E. Burbank,³ then of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, undertook a systematic examination of the magnetograms of the magnetic observatories of the United States Coast and Geodetic Survey for the purpose of comparing the records of seismic disturbances made on them with the records of seismographs in the United States. In addition to the records of the seismographs at the observatories, there were available

² Report of the British Association, 1898.

³ "Earthquake disturbances recorded on the magnetograms at the observatories of the United States Coast and Geodetic Survey." *Terrestrial Magnetism*, September, 1905.

for comparison the records of the Bosch-Omori seismograph operated by the Weather Bureau at Washington, and of seismographs of the Milne type in operation at Baltimore, Toronto, and Victoria.

The effect produced by a seismic disturbance on the magnetogram is characteristic and quite different from ordinary magnetic disturbances. Burbank, in his paper on the subject, differentiates four different types, namely: First, those in which the disturbance begins abruptly and quickly reaches a maximum, dying down gradually (usually the case in nearby earthquakes); second, in which a small preliminary effect precedes the principal portion, in which there are often two or more maxima; third (by far the most common), those consisting of a small diamond-shaped disturbance; and fourth, those in which the trace is simply blurred and broadened.

He found that there were a considerable number of earthquakes which were recorded both by the magnetograph and the seismograph, the time of the record on the magnetographs of the Adie type, with heavy magnets, corresponding closely with the principal portion (large waves) of the seismograph record. In the case of the Eschenhagen magnetographs, with very light magnets, more earthquakes were recorded and the motion usually began a little in advance of the large waves. He also found that some earthquakes were recorded by the magnetograph and not by the seismograph, and vice versa, and that sometimes one variometer of a magnetograph was affected and not the others, as was the experience in the early investigations in Europe. In this connection it should be borne in mind that different seismographs are not equally effective in recording the earth's motion, and that it sometimes happens that only one of two components of a seismograph records a distant earthquake. Mr. Burbank found a considerable number of days on which there were a number of disturbances having the same characteristics as those which corresponded in time with earthquake disturbances. Some of these were traceable to local earthquake shocks felt in different parts of the country. Most of them, however, occurred on days when no earthquake movements had been reported. In later years a large number of these disturbances were recorded on days of severe thunder storms. It is probable that the concussion of the air incident to the electrical discharge was sufficient to shake the ground locally, and thus produce an effect corresponding to an earthquake disturbance.

In 1906, L. A. Bauer ⁴ made a study of the records of the San Francisco earthquake of April 18, 1906, obtained on the seismographs and magnetographs at the magnetic observatories of the United States Coast and Geodetic Survey, and found that the beginning of the disturbance occurred on the magnetographs at the same time as the beginning of the long waves on the seismograph. For some reason the earthquake was not recorded on the magnetograph at Porto Rico.

None of these investigations, however, gave a satisfactory explanation of the manner in which a shaking of the support of the magnet could produce an oscillatory motion. In a paper published in the *Journal of Terrestrial Magnetism* in 1914,⁵ Professor Harry Fielding Reid, of Johns Hopkins University, presented a mathematical discussion of the subject in which he showed that both horizontal and vertical mechanical vibrations are capable of causing oscillations of recording magnets, by reason of the fact that the center of gravity of the suspended magnet does not coincide with the center of suspension, or point about which the system oscillates. He found in particular that there are two periods for horizontal and one for vertical disturbances which will cause marked oscillations of a unifilar magnet; that there are two periods for horizontal and three for vertical disturbances that will cause marked oscillations of a bifilar magnet; and, finally, that there are two periods for horizontal and two equal periods for vertical disturbances which will cause marked oscillations of a magnetic balance. The period of the disturbance must be very close to the proper value in order that the effect may be cumulative; in order, therefore, that a disturbance of small amplitude may make a clear record on the magnetic trace; and this seems to be one reason why the responses of recording magnets to earthquake disturbances are so variable. Reid's results show why it was that the copper bar used by Moureaux in his experiment did not oscillate at the time of an earthquake, although the magnet did. The center of gravity of the copper bar coincided with the center of suspension, and therefore no oscillatory motion was produced by the seismic motion of the ground.

⁴ "Magnetograph record of earthquakes with special reference to the San Francisco earthquake of April 18, 1906." *Terrestrial Magnetism*, September, 1906.

⁵ "The free and forced vibrations of a suspended magnet." *Terrestrial Magnetism*, June and December, 1914.

Reid gives credit to Charles Davison for the first approximately correct explanation of the manner in which a magnet is caused to oscillate by earthquake disturbances. In 1885 Davison pointed out that one end of the compass needle would receive a greater impulse than the other at the time of an earthquake shock on account of its greater mass. Later he showed that in order that a bifilar magnet may remain in a horizontal position, its center of gravity must be at unequal distances from the two points of support.

Lizmar, in 1895, gave a correct explanation of the manner in which oscillations of a unifilar magnet or a magnetic balance may be produced by a seismic disturbance.

The investigations of Burbank and Reid show conclusively that the majority of the peculiar disturbances recorded by magnetographs at the time of an earthquake disturbance are produced mechanically. There is some evidence, however, that there may be a true magnetic disturbance occurring at the time of an earthquake, either resulting from the earthquake movement or from the same cause which produced the earthquake movement. Thus the earthquake of June 12, 1897, disturbed the declination magnet at Bombay, giving fourteen distinct waves in twenty-nine minutes, the natural period of the magnet being 5.33 seconds. Regarding this earthquake, Milne states that a strong disturbance was recorded at nearly every magnetic observatory in Europe which arrived at those stations some time in advance of the large seismic waves, or rather about the time the preliminary tremors were recorded on the seismographs.

Probably the best record of long-period waves is one obtained by C. C. Farr⁶ at the magnetic observatory at Christchurch, New Zealand, in November, 1901. On the morning of November 16th, Christchurch was visited by a severe shock of earthquake. The magnetograph at the Christchurch Observatory, though in adjustment, was not recording at the time. On visiting the observatory shortly after the first shock it was found that the vertical-force instrument had been thrown out of adjustment, while the others remained undisturbed. As it seemed probable that there would be other earthquake shocks than the first, it was decided to attempt to record some of them by running the magnetograph at high speed. This was done from about noon on the 16th until 7:30 p.m. of the 17th, when the supply of paper ran out, and

⁶ "Records of earthquakes on quickly driven magnetographs." *Terrestrial Magnetism*, December, 1902.

from 11 a.m. on the 18th until 6 p.m. on the 20th. When arranged for running at high speed, the drums of the magnetograph revolved at the rate of nearly four millimeters per minute.

In this way four shocks were recorded, all of them perceptible to some of the residents of the Cheviot District. There were also on the sheets many small sudden irregularities which could scarcely be ascribed to ordinary magnetic phenomena. The records of the declination instrument are all of the same general character and show waves of practically the same period of 137 seconds. On the horizontal-force variometer waves having a period of between 41 and 42 seconds were present in each case. The natural period of the magnets was 10.34 seconds in the case of declination, and 13.07 seconds in the case of horizontal intensity. The Milne seismograph in Wellington showed a series of comparatively small tremors during most of the periods when the magnetograph was being driven at high speed. There was one small tremor corresponding to one of the four disturbances recorded on the magnetograph, but there were many tremors larger than this on the seismograph record which were not recorded at all by the magnetographs. It seems possible that this may have been a real magnetic effect of the earthquakes.

Yamasaki, in a paper in 1901 on the relation between seismic and magnetic disturbances, stated that investigations in Japan covering a period of ten years showed that magnetic disturbances almost always occur a few days before violent earthquakes.

G. B. Rizzo,¹ from a study of the records obtained on the magnetographs of numerous observatories at the time of the Calabrian earthquake on September 8, 1905, concludes that the earthquake disturbed the majority of magnetographs within 1900 kilometers of the epicenter, the time of the disturbance, within the limits of the error of determination, coinciding with the principal portion of the seismic disturbance, and that it was probably produced by the movement of the ground at the site of the observatory. He suggests that this motion of the ground may have been transmitted to the magnet either directly (mechanically) or indirectly through the modification of the local magnetic field for a brief period. He points out that great volcanic eruptions which alter profoundly the electrical condition of the earth and air are sometimes accompanied by notable magnetic disturbances, as in the case of

¹ "Sopra le perturbazioni magnetiche dovute al terremoto della Calabria dell' 8 Settembre, 1905." *Terrestrial Magnetism*, September, 1906.

the eruption of Mont Pelée in 1902. In the case of this eruption, which was made the subject of special study by L. A. Bauer, it was found that a severe magnetic disturbance began abruptly at the time of the eruption, as nearly as could be determined from the information obtainable, and that this disturbance was recorded all over the globe, the times of beginning at the different magnetic observatories showing a variation of only a few minutes. Rizzo suggests that an earthquake may be accompanied or preceded by a disturbance of the electrical state of the earth or air, which may affect the earth's magnetic field.

From the cases cited, it seems possible that there may be at times a real magnetic disturbance associated with an earthquake, but the evidence available is as yet so limited that it is impossible to say conclusively whether the association is accidental or whether the two phenomena are traceable to the same source.

To summarize: A great many earthquakes are recorded mechanically by magnetographs, the disturbance of the magnets usually occurring at the time of the principal portion of the seismic motion, though in some cases it begins a little earlier.

Magnetographs appear to be more sensitive to certain types of earthquake waves (particularly local shocks) than some seismographs.

It is possible that a real magnetic disturbance may sometimes be associated with an earthquake, though the evidence as yet presented is not conclusive.

GREAT EARTHQUAKE AND TIDAL WAVE IN SOUTHERN
MINDANAO, P. I.

By MIGUEL SADERRA MASÓ

On August 15, 1918, at 12^h 20^m 28^s (G. M. T.), a great seismic disturbance was recorded at Manila, the origin of it being at a distance of about a thousand kilometers. Subsequent telegraphic reports showed that the whole island of Mindanao had been violently shaken by an earthquake of very long duration. The epicenter, as far as it could be inferred from later reports, was in the Celebes Sea between the 124th and 125th meridians east, and the parallels 5° and 6° north.

The number of aftershocks during the successive days was so great that the Observatory at Manila, a thousand kilometers distant, recorded fifty-one of them to the end of August. At the station of Butuan, situated in Mindanao at about 450 kilometers north northeast from the center a Wiechert seismograph recorded 599 during the same period, about 250 of which occurred on the 15th and 16th.

In September, word came from the Philippine constabulary officers stationed at Lebak and Glan, stating that the earthquake had caused great damage in the southern country, facing Celebes Sea, between Cotabato and the Davao Gulf; and that it had been followed by a tremendous sea wave which swept the whole coast between Lebak and Glan, completing the destruction caused by the shocks. All the devastated country is inhabited by Moros and wild tribes, so the real amount of damage and number of casualties is not yet, and probably never will be, known. The following reports published by the local press refer only to the Sarangani Bay and to the vicinity of Port Lebak, where constabulary posts exist and some white men live. The town of Glan is situated at the entrance of Sarangani Bay, while Port Lebak lies about a hundred miles to the northwest:

Captain Malone of the Philippine constabulary stationed at Glan, Cotabato, reports that the earthquake which occurred on the night of August 15th, last, destroyed all houses in Sarangani Bay and so far as known killed forty-six people. He reports that the earthquake lasted for three minutes and ten seconds and was later followed by a tidal wave reaching as high as twenty-four feet at some points and at the constabulary station at Glan to the height of

eighteen feet, thereby destroying all of the houses that had been shaken down by the shock and drowning a number of people, cattle, horses and other domestic animals and destroying all of the food supply of those living near the beach and all of the crops on the low lands. All native vintas were either destroyed or taken out to the sea. Large rivers were completely obliterated and new ones created. He further reports that a slide occurred on one of the large mountains adjacent to Sarangani Bay and it is his opinion that a number of wild people living at the foot of the mountain were buried, but as yet no definite reports have come in.

L. B. Kidwell, who has a saw-mill at Port Lebak, reports that the tidal wave at his place was between six and eight feet, killing six people and carrying a number of logs quite a distance inland. Light earthquakes have been almost continuous since August 15th both at Sarangani, Lebak and Cotabato, but no further damage has been done.

Another report says:

To the south of Port Lebak for some forty miles (I know nothing farther south) there was a tidal wave variously estimated at from twenty to twenty-five feet by Moro loggers who know what these measures are. Several Moros were drowned.

THE NEW ZEALAND EARTHQUAKE OF AUGUST 6, 1917

By P. G. MORGAN

About 3:22 a.m. (New Zealand mean time)¹ on Monday, August 6, 1917, an earthquake was felt over the greater part of the North Island. The shock was more severe in the Wairarapa and East Wellington district than elsewhere. At Castlepoint the lantern apparatus of the lighthouse was thrown out of position and much damaged. Many chimneys were overthrown in the Eastern Wairarapa district, while at Masterton and Carterton many chimneys were partly destroyed, and crockery, etc., thrown off shelves. At the Manawatu Gorge a slip took place, which blocked the railway line. At Wellington people were, in general, aroused from sleep, clocks stopped, and a few articles were thrown off shelves. A rumbling noise was heard by some observers. Among the more distant points where the shock was distinctly felt was Auckland. It was not felt by residents of Christchurch (South Island), but was clearly registered by the seismograph at the meteorological observatory. The chief motion recorded was very large and lasted three minutes. Tremors began at 3:21 a.m., and extended over an hour.

During the next few days numerous after-shocks were felt in the Wairarapa district. Some of these were severe, especially one, that occurred about 3:40 a.m. (or slightly later) on Tuesday, August 7th. This was felt over the whole eastern part of the North Island. Among the localities reporting the shock were Whakatane (Bay of Plenty) and Waihi (in Ohinemuri County, near the north end of the Bay of Plenty).

There can be no doubt that these various earthquakes originated in or near a zone of faulting that lies parallel to the east coast of the North Island (from Cape Palliser to East Cape) and about two hundred miles distant. The severe earthquakes that occurred in the Gisborne district during October and November, 1914, had their origin in the same belt. The notable earthquake of August 9, 1904, and many

¹ New Zealand civil mean time is 11 hrs. 30 mins. ahead of Greenwich mean time. A proposal to advance it to 12 hrs. ahead of Greenwich has lately been made, and is receiving strong support.

others experienced in New Zealand are also to be ascribed to crustal movements in this belt.

Most of the statements made in the above paragraphs are founded on newspaper reports published on August 6th and the next few days.

Since the above was written Mr. George Hogben, M.A., C.M.G., has read a paper before the Geological Section of the Wellington Philosophical Society in which he states that the earthquake of August 6th (August 5th if Greenwich time be used) originated in a spot approximately 296 kilometers (184 miles) eastward of Wellington, and 456 kilometers (283 miles) northeast of Christchurch. This gives an origin somewhat nearer the coast than any of the previous earthquakes mentioned above.

ERUPTION OF MOUNT NGAURUHOE, NEW ZEALAND,
OCTOBER-NOVEMBER, 1917

By P. G. MORGAN

During the latter part of October, 1917, the volcanic cone of Ngauruhoe, in the central part of the North Island of New Zealand, showed increasing signs of activity. These were first observed about the 17th. On the night of Tuesday, October 23, an outburst of considerable intensity took place. A newspaper account states that huge clouds of ash and steam were emitted from the crater, and numerous earth tremors were felt. Clouds prevented observation for some days, but a still more violent eruption began about 9 p.m. on Saturday, November 2nd, and continued almost without cessation until 3 p.m. on Sunday. At times large masses of red-hot lava were thrown out of the crater, and according to one account lava actually flowed down the sides of the mountain. On the other hand persons who ascended the mountain on November 11th stated that no lava was emitted, and that the dark stream running down the northwest side was not lava, but black scoria ash, which from a distance had the appearance of a lava stream. The earth tremors were very strong, and felt for great distances from the mountain, for example at Taumarunui, $26\frac{1}{2}$ miles to the northwest. Articles on shelves at the prison camp, six miles away, were thrown on the floor. Houses trembled, and many panes of glass were broken. The fiercer outbursts were accompanied by violent detonations and long reverberations. Until November 11th eruptions of varying intensity took place, but from November 12th the newspapers available give no particulars, and presumably noteworthy outbursts ceased to take place. The chief point of observation was Waimarino, a railway station $13\frac{1}{2}$ miles west of the summit of Ngauruhoe.

Although the flow of lava from Ngauruhoe during the eruption is not authenticated, there is no doubt that masses of molten rock were ejected, and in falling assumed the form of pancakes. Mr. A. J. Baker, Public Works Engineer at Taumarunui, who ascended the mountain after the eruption, saw flattened masses of dark andesitic lava six feet

in diameter. The last record of a lava flow from Ngauruhoe was during the eruption of 1869.¹

Some of the boulders ejected during the eruption are said to have been of twenty-five tons weight. Extremely large boulders were observed half a mile to the north of the crater, and stones of considerable size reached the flat country on the western side of the mountain. It is reported that the crater was considerably altered in shape during the eruption.

¹ Thomas, A. P. W.: "Notes on the Volcanic Rocks of the Taupo District and King Country." *Transactions New Zealand Institute*, 20, 306-311, 1888. See p. 308.

AFTERSHOCKS OF THE SAN JACINTO EARTHQUAKE OF
APRIL 21, 1918

From data collected by HOMER HAMLIN of Los Angeles, California.

Following the earthquake of April 21, 1918, at San Jacinto and Hemet, Cal., reported in this BULLETIN, volume 8, pages 45-73, aftershocks continued for several days throughout a large part of the area affected by the main shock. Some of these aftershocks are mentioned at page 60 of the report, but most of such disturbances have been accepted as a well known phase of all severe earthquakes, and but little account has been taken of them. The shocks mentioned in the following records appear to belong with the aftershocks of the San Jacinto earthquake, and are therefore brought together here under one head. No attempt has been made to gather a full record of all such aftershocks.

At Corona, Riverside County, Cal., a sharp shock was felt April 22, 1918, at 2:15 p. m. It is said to have lasted for nearly two minutes, and to have been violent enough to upset small objects, to crack chimneys, and to throw down plaster.

A mile and a half northwest of Wildomar, Riverside County, on April 26, 1918, at 10:30 a. m., there were three shocks within half a minute felt by everyone. There was the usual rattling of doors, windows, and loose objects, but no damage was done.

At Calipatria, Imperial County, Cal., a slight shock was felt by everyone on April 28, 1918, at 2:30 p. m. It lasted four or five seconds, but caused no damage.

On April 30, 1918, about 9:30 p. m. earthquakes occurred over a wide area in southeastern California, including the Imperial Valley, the eastern part of Riverside County as far as the Colorado River at Palo Verde and Yuma, Arizona. It seems probable that this was also an aftershock of the San Jacinto earthquake of April 21st, but there are reports enough to identify it as a distinct shock that was clearly discerned over a wide area, and especially well defined from Hemet southward along the axis of the San Jacinto fault and extending into Mexico. Reports collected upon this earthquake by Mr. Homer Hamlin come from the points mentioned in the table below.

IMPERIAL VALLEY EARTHQUAKE OF APRIL 30, 1918.

Location	Duration	Intensity R.-F. Scale	Notes
Ames (N.W. of Glamis).....	30 sec.	.....	Three shocks preceded by thunder
Brawley	15-30 sec.	IV-V	Continuous
Calipatria	10 sec.	IV	Continuous
Calexico .....	.....	VII	.....
Coachella	10-15 sec.	V+	.....
Descanso, S. Diego Co.....	3 sec. each	IV	Two shocks
El Centro	1¼ min.	VII	After 9:30 the shocks "came in droves" and kept it up until May 2d
Glamis, Imperial Co.....	3 sec.	IV-V	One shock
Heber .....	.....	V-VI	See text below
Hemet	"all night"	.....	Small shocks numerous more than a week after April 21st
Holtville, Imperial Valley.....	10 sec.	V	Continuous
Imperial .....	.....	VI	.....
Mecca .....	.....	IV+	Two shocks
Ogilby	few secs.	V	One shock
Palo Verde	30 sec.	V	One shock
Picacho, Imperial Co.....	2 min.	VI	Two shocks
Potholes	10 sec.	IV	One shock
Warner Springs	4 or 5 sec.	V	Shocks for ten days before
Wister	2 sec.	IV	One shock
Yuma, Ariz.....	5 sec.	IV	One shock

The following extracts are from a letter written by Mr. H. P. Messenger, of Heber, Cal., to Homer Hamlin, regarding the earthquake of April 30th:

HEBER, CAL., May 5, 1918.

My Dear Mr. Hamlin:

I should have replied to yours regarding several of these other quakes, but I have been extremely busy of late, and have hardly had time to do any writing. Since that bad one on the 21st of April we have had a more or less continued shaking down here. I am sorry I did not put down the dates, but about a week ago around 8:30 in the evening we had a very decided shock that seemed to me a lot worse than the one on the 21st. It came with a distinct rumble (to me the rumble always seems to come from the southwest), and the quake was upon us, and it was a corker, too. I grabbed the lamp in time to save it from tumbling off the table; a picture came crashing down, and as I got out of my chair the pictures on the north and south walls would alternately swing out into the room and the ones on the east and west walls swung and rubbed against the walls. Several dishes were overturned. So far I have never noticed a rumble

during or after a quake. That same night I was wakened four or five times by different quakes. Some would have a rumble and hardly any shake. One came the other morning at about 5:30 a.m. I heard a slight rumble and the east end of the house gave a slight creak, and it must have been at least three-fifths of a second before I felt or heard the other end of the house. One of the men said he heard the rumble in the southeast, but I did not hear it.

Another feature of the one on April 21st was that long after the actual shaking was over there appeared a slight undulating as if one were on a ship. After that motion was imperceptible I watched a door that kept swinging back and forth through an arc of an inch at the outer side of the door. As it kept up so regular and active and did not die down for a minute I am sure the earth was still under a disturbance.

The only humorous feature was that Mrs. Messenger grabbed the baby up and rushed outside; and (afterwards) whenever a car was heard coming down the road she would mistake the exhaust rumble for a quake and make a mad sprint for the child and rush outside again. I must admit that they are a rather hair-raising affair with the house shaking to beat the band and it getting worse every second.

I went through the one we had three years ago and it sure twisted things up proper. . . .

Very truly yours,

H. P. MESSENGER.

On May 1st, shocks were felt at 7:44 a.m. at the following places: at Calexico there was one shock with an intensity of about IV; at Holtville, Imperial, and Picacho the intensity seems to have been about IV. Replies to inquiries sent to Corona, Wister and Yucaipa show that the shock was not observed at those places. At Calexico shocks were also noted as follows: on May 1, 12:07 a.m., 12:59 a.m. 1:07 a.m., 5:40 a.m. Other shocks were observed at that place, but no note was made of the time.

At 9:25 p.m. on May 2d, a shock with an intensity of IV-V was observed by several persons at Campo in San Diego County.

At Coachella on May 8, 1918, two slight shocks were felt at 12:20 p.m. by persons at rest.

At Heber in the Imperial Valley on May 8th one light shock was felt at 2:30 a.m. by persons at rest.

Six miles southeast of Aguanga, Cal., one light short shock was felt at 4 p.m. on May 9, 1918.

At Hemet, Cal., a sharp shock was felt generally at 12:20 p.m. on May 11th.

At Calipatria, Cal., a shock lasting about ten seconds occurred May 11th at 1:05 a.m. No damage was done, but observers note that the shock was of an intensity of VI.

Three miles east of Heber in the Imperial Valley, a shock was felt at 1:30 a.m., May 12, 1918, lasting ten seconds.

At Calipatria, Cal., another shock was felt generally at 10:54 p.m. on May 12th, lasting four or five seconds.

At 9:45 a.m. on May 16, 1918, a shock was felt one and a half miles northeast of Hemet, Cal. Dishes, doors, and windows rattled, and ceilings cracked. The shock lasted about three seconds and was accompanied by a roaring sound. No damage was done.

Three and a half miles east of Heber, Cal., an earthquake was generally felt at 6:47 p.m. on May 20, 1918. It lasted only two or three seconds, but it was strong enough to cause the swaying of buildings, and was accompanied by a rumbling sound.

SEISMOLOGICAL NOTES

White Bluff, Wash., April 18, 1918.—An earthquake was felt at White Bluff, about seven miles west of Spokane, Wash., shortly after 1 o'clock p.m. on April 18th and lasted about four seconds. It rattled dishes and windows and was accompanied by a rumbling noise. A. M. Jung, curator of the seismograph at Gonzaga University at Spokane, reports that the time at his station was 1:13 p.m.

Simi, Ventura County, Cal., May 24, 1918.—A light shock was felt by persons at rest one and a half miles west of Simi, Cal., on May 24th about 8 p.m. No damage was done.

Benton, Cal., June 4, 1918.—Two gentle shocks were observed at Benton, Mono County, Cal., at 9:03 a.m. on June 4th, and lasted about ten seconds. The intensity appears to have been about IV, R.-F. scale.

Southern California, June 6, 1918.—An earthquake was felt June 6th, about 3:30 p.m., at several widely separated places over Southern California. For the following data we are indebted to Homer Hamlin, civil engineer, of Los Angeles: At Oak Grove, Riverside County, two shocks were felt, generally with swaying and creaking of buildings, and clouds of dust rose on the neighboring mountains. At Aguanga, thirty miles southeast of San Jacinto, this shock is said to have been the most severe experienced after that of April 21, 1918. Two distinct shocks were observed, but no damage was done. Four and a half miles southeast of Hemet the shock was felt by everyone, and it was sharp enough to crack plaster on the walls, to loosen rocks from the mountain side, and to crack the ground around large trees. At Hemet two distinct shocks were felt by everyone, but they do not seem to have been as severe as they were southeast of that town. At Corona, Riverside County, it was felt generally, and is supposed to have had an intensity of about IV, and was accompanied by subterranean rumblings.

At Baptiste, twenty-five miles southeast of Hemet, two quick, bumping shocks were distinctly felt by everyone, and were preceded by a rumbling sound.

At Coachella there seemed to be a few light tremors, ending with one heavy jerk. It was felt generally, and caused the swaying of buildings and trees; the surfaces of ponds were disturbed as if by something thrown into the water.

It was felt at Wister, eight miles west of Niland, as a single shock.

In the Cuyamaca mountains, twelve miles north of Descanso, two members of the U. S. Forest Service heard a distinct rumbling five seconds before the shock was felt. There was but one shock at that place, and that lasted six seconds.

At Noria (formerly Gray), Riverside County, two shocks are reported, lasting four seconds, and felt by everyone.

In the Imperial Valley it was felt by everyone three and a half miles east of Heber, but not at Glamis.

At Warner Springs, San Diego County, the shock lasted three seconds and was generally felt.

At Los Angeles the shock was felt by many, especially by persons at rest or on fourth or fifth floors. Pencils lying on a drafting board were rolled about.

Cahuilla, Cal., July 7, 1918.—At about 5:30 p.m. on July 7, 1918, a slight earthquake was felt at Cahuilla, Cal., by persons at rest. The intensity was estimated to be about III, R.-F. scale.

Cairo, Egypt, July 16, 1918.—British newspapers report a severe earthquake, but without damage, at Cairo on July 16, 1918, at 10:10 p.m.

Olancho, Cal., July 17, 1918.—A distinct earthquake shock was felt twelve miles southeast of Olancho, Inyo County, Cal., July 17, 1918. It was observed by persons at rest and lasted one minute, rattling dishes, doors, windows, etc. No damage was done; the exact hour of the shock is not stated.

Panama, July 20, 1918.—The Associated Press reports earthquakes in the region west of Panama on July 20, 1918, but without damage.

Johannesburg, S. Africa, July 21, 1918.—The Associated Press dispatches report several earthquake shocks on July 21, 1918, with damage to the mines.

Los Angeles, Cal., September 16, 1918.—A gentle earthquake was reported from Los Angeles on September 16, 1918, at 9:27 p.m., lasting for twenty seconds.

Pine Bluff, Ark., October 4, 1918.—The newspapers report earth tremors at Pine Bluff, Ark., at 3 o'clock a.m. on October 4th.

Porto Rico, W. I., October and November, 1918.—A very heavy shock of earthquake was felt in Porto Rico at 10:14 a.m. on October 11, 1918. Minor shocks were felt in great number for over a month, with pretty strong ones on October 24th at 11:43 p.m. and on November 12th at 5:44 p.m. The first shock caused much damage, which was increased by that of the 24th. The people were greatly alarmed, and at the request of the Secretary of War, who directs the affairs of the Insular Government, Professors Harry Fielding Reid and Stephen Taber went to the island to study the disturbance. After they had been over about two-thirds of the island they made a preliminary report to the Governor, which was published in the local papers, and from which we make the following extracts:

"We believe the earthquakes were due to fractures of the rock in the northern part of Mona Passage, not far from the northwestern part of the Island of Porto Rico, and that the fracture which caused the shock of October 11th was accompanied by a small vertical displacement of a very limited area of the sea bottom, causing the sea wave which rose along the shores soon after the shock. Displacements of this kind are not uncommon, and portend no great disaster to Porto Rico. The shocks, though severe, were distinctly less violent than many shocks that have occurred in other parts of the world; for example, than the Charleston earthquake of 1886, or the California earthquake of 1906.

"The damage done by the shocks was greatest in the western part of the island and diminished progressively, though not uniformly, towards the east. On soft alluvial soils it was greater than on more solid foundations in the same neighborhood.

"The character of the construction of the buildings was responsible for the great destruction wrought. Buildings of 'mamposteria' suffered most, and brick buildings nearly as much; the extremely poor quality of the mortar used (in some cases it was scarcely stronger than dried mud) made these buildings exceptionally weak. Next in order came block concrete buildings and then those of concrete not reinforced. Well-made reinforced concrete buildings suffered no serious injury even in the regions where the shock was strongest. Wooden buildings and the small native huts, by yielding to the shock, were not damaged. . . .

"The sea wave, which followed the earthquake of October 11th, was of course confined to the coasts. Near Point Borinquen it attained a height of about twenty feet and drowned several people; it destroyed some native huts and some cocoanut trees. At Aguadilla a number of people were drowned and native huts were carried fifty or a hundred feet inland. At Mayaguez huts were moved. No damage seems to have been done by the wave elsewhere.

"All strong earthquakes are followed by aftershocks, which gradually die out in strength and in number. Sometimes there is but a single strong shock; sometimes, as in the recent shocks here, there are several. But strong shocks never continue indefinitely; quiet is always restored after a more or less short time. The aftershocks here have grown infrequent and very light; and, although the general knowledge of earthquakes does not justify a definite prediction, we think the indications are that the present disturbance is reaching its end. There is certainly no special reason for expecting another strong shock in the near future."

Corfu, Wash., November 1, 1918.—A. M. Jung, seismological observer at Gonzaga University at Spokane, Wash., communicates the following note from C. H. Aldrich of Corfu, a station on the Chicago, Milwaukee Railway 135 miles west of Spokane, in regard to an earthquake at that place: "The first shock was on November 1st, between 9:15 and 9:30 a.m. This was the most severe and lasted several seconds; it shook goods from the shelves and caused landslides for several miles along the hills. We have had on an average about three shocks every twenty-four hours since, but lighter." The intensity is estimated at IV of the R.-F. scale.

Italy, November 10, 1918.—An earthquake is said to have occurred November 10, 1918, in the mountains east of Florence. The village of Bagno di Romagna was damaged, and at the village of Santa Sofia a church collapsed, killing eight persons.

Jamaica, W. I., November 11, 1918.—In the district of Portland, Island of Jamaica, an earthquake was felt November 11, 1918. The exact time is not given; no damage was done.

Venice, Cal., November 19, 1918.—Two or three earthquake shocks were felt at Venice, Ocean Park, Santa Monica, Sawtelle, Hollywood and Redondo at 12:15 p.m. on November 19, 1918. Dr. James T. Brown of Venice reports that two shocks were felt by everybody at that place, and that they were accompanied by sounds resembling explosions. Similar explosion-like sounds were observed in Santa Monica Bay.

Tahiti, November 20-22, 1918.—Several earthquakes are reported from the island of Tahiti and at sea sixty miles off the Society Islands, November 20 to 22, 1918.

Copiapó, Chile, December 4, 1918.—A severe earthquake occurred in the province of Atacama, Chile, December 4th, affecting the area between Vallenar and Taltal in the province of Antofagasta. Much damage is said to have been done to railways and other property, but details are lacking. The shocks were recorded by the seismographs at Vancouver, Ottawa, Washington, and elsewhere.

New Seismological Station.—Central America is a region of very considerable seismic activity, but it has always been difficult to obtain accurate and scientific reports of the disturbances occurring in that region. It is therefore gratifying to know that a seismological station is to be established there, as will be seen from the following note recently received from the Director of the Georgetown Seismological Observatory:

"The establishment of a coöperative seismological station in Guatemala City, Guatemala, has been determined upon by Francis A. Tondorf, S.J., Director of the Georgetown Seismological Observatory. This station will be in charge of Mr. Claudio Urrutia, chief consulting engineer of the Guatemalan government. It is expected that reports from this center will be available on or about March 1st. Bulletins will be dispatched directly from Guatemala."

Two Unique Records.—According to a letter recently received from Dr. Otto Klotz, Director of the Dominion Astronomical Observatory, Ottawa, Canada, the public of that city had been advised that the abdication of the Kaiser and the signing of the armistice would be announced, as soon as the news arrived, by two blinks on the electric light circuit throughout the city for the first event and four blinks for the second event. As the seismograph records photographically and as the city light is used, obviously any blinking of the light would be recorded, as is shown on copies of the two seismograms kindly sent by Dr. Klotz.

Shoddy Buildings.—The manner of constructing buildings, in any country subject to seismic disturbances, is one of great importance and it is hoped that something will be done soon toward making more stringent laws concerning building design and construction.

A prominent California architect, to whom was sent a reprint of the articles on the San Jacinto earthquake printed in the preceding number of this BULLETIN, writes as follows on this subject:

I especially appreciate the photographs of the wrecked buildings and am going to use them in the future in an attempt to get some improved legislation on the architects' license law in this state, which will make it a crime to construct such shoddy buildings as these pictures evidence.

The architects endeavored at the last session of the legislature to have some improvements in our license law, but it was difficult to impress the members of the legislature with the importance of holding someone responsible financially and criminally for the results of the careless and shoddy construction of buildings. These photographs would have been most convincing.

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Ithaca, N. Y. Cornell University—Seismograph Station, Department of Geology. Reports nos. 84 to 88, August 1 to November 30, 1918.

La Paz, Bolivia.—Boletin Sismico del Observatorio del Colegio San Calixto (PP. Jesuitas). Reports nos. 1 to 18, 20 to 41, January to October 19, 1918.

Ottawa, Canada.—Earthquake Station, Dominion Astronomical Observatory. Reports 12 to 27, from July 1 to November 30, 1918.

Washington, D. C.—Georgetown University. Seismological Bulletin, Department of Geology, nos. 40 to 43 bis bis, from July 1 to October 31, 1918.

EUROPE

Barcelona, Spain.—Estacion Sismica del Observatorio Fabra de la Real Academia de Ciencias y Artes, nos. 48 to 53, from May 1 to August 31, 1918.

Coimbra, Portugal.—Boletin Sismico do Observatorio da Universidade, nos. 5 to 8 cont. from May 1 to September 30, 1918.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletin of the Observatory, nos. 7 to 30, from March 1 to September 30, 1918.

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G. Agamennone.—“Sulla natura del 10 impulso del terremoto Marsicano del 1915.” Est. Reale Accademia dei Lincei, 27, 65-69. Roma, agosto, 1918.

Octavio Bustamente.—“Jefe del Servicio Meteorologico y Sismologico Mexicano.”—*Boletin Mensual del Observatorio Meteorologico y Sismologico Central de Mexico*, Tacubaya, D. F., nos. 1, 2, 3 y 12, 1918.

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F. Omori.—“Vibration of reinforced concrete chimneys.” “On the relation between the duration of the preliminary tremor and the epicentral distance for near earthquakes.” *Bulletin of the Imperial Earthquake Investigation Committee*, 9, no. 1, Tokyo, March, 1918.

J. Scherer.—*Bulletin Annuel de l'Observatoire Météorologique du Séminaire*—College St. Martial, Port-au-Prince, Haiti, An 1917; *Bul. Sismologique*, pp. 129-131. (Haiti), 1918.

Weather Bulletin, December, 1917.—Catalogue of Philippine earthquakes, 1917.

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- I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. **Fairly strong shock**: general awakening of those asleep; general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.
- VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. **Very Strong shock**: fall of chimneys, cracks in walls of buildings.
- IX. **Extremely Strong shock**: partial or total destruction of some buildings.
- X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

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